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Canadian Urban Modelling: A Review of Innovative Urban Modelling Techniques

Prepared for the
Urban Transportation
Research Branch
of Canadian Surface
Transportation Administration
Transport Canada

Montreal, Quebec
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March 1979

DISCLAIMER

THE VIEWS EXPRESSED IN THIS PAPER ARE THOSE OF THE AUTHOR. THEY DO NOT NECESSARILY REFLECT THE VIEWS OF THE URBAN TRANSPORTATION RESEARCH BRANCH, CANADIAN SURFACE TRANSPORTATION ADMINISTRATION, TRANSPORT CANADA.

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1. INTRODUCTION

The purpose of this report is to detail the findings of a review of Canadian urban modelling techniques which was performed by the IBI Group for the Urban Transportation Research Branch (UTRB) of Transport Canada.

1.1 PROJECT OBJECTIVES

The original aim of the review as stated in the request for proposal was "to provide a clear understanding of what work currently exists in Canada in a final product form and to use the best of that work as a basis upon which and around which to build future projects". The objectives of the study in light of this aim were as follows:

1. "Identify the available, documented, computer programs not forming part of one of the recognized international packages."

2. "Of the above, select those which are believed to represent a clear advance in the state-of-the-art of urban modelling in Canada based on analysis by a selected review panel."

The ultimate purpose of the identification of those programs which represent clear advances is that they would form the core of a modelling package which would be sponsored or disseminated by the Urban Transportation Research Branch. The UTRB was concerned about the lack of cross-fertilization among various developers of models in Canada and the lack of information on new techniques on the part of potential users. Continued assistance and support for model development and dissemination of information would help to overcome this difficulty.

However, some time after the study was initiated, it was decided that the UTRB would terminate its operations at the end of March, 1979. This

decision made it necessary to modify the basic aims of the study. Instead of identifying a number of models which would form the core of an urban modelling package, the aims of the study were changed to investigate the state-of-the-art across Canada and to disseminate information to potential users on recently developed and existing established models.

1.2 PROJECT PROCEDURES

This project went through four clearly defined phases. In the first phase, through a survey and by other methods, sources of urban models in Canada were contacted and invited to submit models or modelling packages that they might have developed. In the second phase, these were initially screened to select those that met the requirements of this project. In the third phase, an expert panel met and reviewed the remaining models to determine which best met the criteria of this project. Finally, the fourth phase was an information dissemination phase made up of the preparation of this report and the holding of a number of seminars in various cities across Canada.

1.3 MAJOR RESULTS

Basically, the project team found that there was a great deal of activity in urban modelling across Canada. Over 70 models were reviewed, 25 were submitted to the panel for further review, and 11 were selected by the panel for specific dissemination and publication.

Although there was a great deal of effort going on in this field, there was found to be more concentration on certain areas than others. For

example, land use allocation, trip modal split and assignment models were well represented in the models submitted and chosen. Less well represented were trip generation and distribution and there was a very limited availability of urban goods movement models.

It was also noted that only certain types of authors document their programs in a way sufficient to allow other people to use them. It was found that sufficient documentation was normally prepared only by authors working in academic environments and on Transport Canada-sponsored projects.

It was also found that there is a real need for information flow in this area and that this need is not being met. This information gap is filled in the short term by this report but in the longer term, various avenues of information dissemination have been discussed including, co-operative efforts between Transport Canada and the Provinces, possibly working through the Roads and Transportation Association of Canada.

1.4 ORGANIZATION OF THE REPORT

The second chapter of this report discusses the survey which was used to initially identify the urban modelling techniques that are both in use and under development by various researchers and agencies across Canada. Appendix A contains a listing of the models and modelling packages identified during the course of the survey.

The third chapter describes the process used to identify those models which met the requirements of the project and for which detailed

documentation was available. These models were then evaluated by a panel of model users from across Canada with input from both client and consultant staff. The panel members selected a number of these models for dissemination based upon this evaluation. Standard form descriptions were developed by the consultant teams for the selected models; the format for these standard descriptions is provided in the third chapter. Appendix B contains these descriptions for the selected models and Appendix C similar descriptions for other established Canadian models and modelling packages. Appendix D provides a list of the panel members who reviewed the various models.

The findings of the study are presented in the fourth chapter. Included in this chapter are brief discussions on: the selected models; the areas of interesting research which were identified by the review process but which were not sufficiently developed for selection; and gaps in urban modelling which were found to exist and a discussion of how these gaps might be filled by models from the United States or elsewhere.

The fifth and final chapter summarizes the conclusions of the study team. It includes a discussion of the type of activity found, where gaps in research were detected, and suggests possible methods for further dissemination of urban modelling information amongst the various potential users.

EXHIBIT 1

SURVEY RESPONSE FORM

URBAN MODELLING TECHNIQUES

PRINCIPAL RESEARCHER:

ORGANIZATION/AGENCY:

ADDRESS:

TELEPHONE NO.:

DESCRIPTION OF TECHNIQUE:

WHEN DEVELOPED:

APPLICATION(S):

AVAILABILITY OF PROGRAM(S):

LANGUAGE:

COMPUTER SYSTEM:

TYPE OF DOCUMENTATION AVAILABLE:

Please Return To:

IBI Group
40 University Avenue
Toronto, Ontario
M5J 1T1

2. SURVEY OF URBAN MODELLING TECHNIQUES

In order to identify the urban modelling computer programs which have been and currently are being developed across Canada, a questionnaire was sent to over 180 researchers and model users in both public and private organizations. The mailing list for this survey was developed jointly by UTRB and consultant staff. One source consulted was the "Survey and Inventory of Computer Based Urban Transportation Planning Techniques" that had been prepared by the Centre de Recherche sur les Transports of the Universite de Montreal for the Urban Transportation Research Branch in November, 1975. This includes a list of municipalities and others using such techniques.

A copy of the response form which was enclosed with each letter is presented in Exhibit 1. Roughly sixty-five responses were received over the course of several months. Of these, thirty-five included information on one or more urban models.

Survey forms were not sent out to workers at the University of Toronto and York University. For these two institutions there had been a recent cataloging of transportation modelling techniques (J.Farnady, "A Catalogue of Transport-Related Computer Programs, Packages and Major Data Sets", University of Toronto/York University Joint Program in Transportation, June, 1978). This catalogue included model descriptions and short descriptions of relevant computer programs.

Through the survey responses, the examination of the two publications listed above, and a review of Canadian journals and periodicals, over sixty urban modelling computer programs were identified. This figure does not include the numerous programs available from the Ministry of Transportation and Communications of Ontario as part of their Transportation Planning System (TPS) and their Simplified Transportation Planning Computer Package (STPCP, also known as System 033).

All of the models and modelling packages that were identified through the complete survey process are listed in Appendix A. For the purposes of this listing the models were grouped into the following categories:

- land use models
- travel demand models
- modal split models
- road and transit assignment models
- comprehensive transportation models
- operations related models
- urban goods movement models
- evaluation models
- others

Under each category, the models are listed by principal researcher and organization. A very brief description of each model is given as well as information on the type of documentation available and on previous model applications. The types of applications which are mentioned include: illustrative ones that examined sample problems; research applications which used real data but were not meant to provide any input into an actual decision-making process; and practical applications where the model output was used in a decision-making process.

EXHIBIT 2

SURVEY RESPONSES

		REPLIES		
GROUPS	QUESTIONNAIRES	POSITIVE	NEGATIVE	TOTAL
UNIVERSITIES	60	15	4	19
PUBLIC AGENCIES	80	15	20	35
PRIVATE ORGANIZATIONS	42	5	6	11
TOTALS	182	35	30	65

Generally, the response from academic institutions was more full and complete than from others. Government agencies were second in terms of their investment of resources to document and write up models and techniques. Consultants, except when they are specifically developing a technique to apply in several cases, do not normally do this. They often seem to develop techniques for one application only.

A tabulation of the various responses is given in Exhibit 2, opposite.

3. REVIEW OF URBAN MODELLING TECHNIQUES

The original objectives of this study, as stated earlier, were twofold. The first objective was to identify available Canadian computer-based urban models which were not part of a recognized international package. The second was to select from the above models those which represented "a clear advance in the state-of-the-art of urban modelling in Canada based on analysis by a selected review panel." To achieve these objectives a two stage review process was used to examine the results of the survey described in the previous chapter.

3.1 INITIAL REVIEW

In the first stage of the review process, all of the models identified by the survey were reviewed initially by consultant staff. A screening process was undertaken, using the criteria below, to identify those models which should be presented to the selection panel for review and evaluation:

- the model was developed in Canada
- a useable, documented computer program was available for the application of the model
- the model was not simply an application of a well known technique (e.g. gravity models, simple regression equations, etc.)
- the model was not part of an established package (e.g. the computer programs available from the Ministry of Transportation and Communcations, Ontario).

The information that was used to assess the models in terms of the above criteria was obtained from: the completed questionnaires which had been submitted; any documentation supplied by the principal researcher in addition

to the questionnaires; published papers on either the model structure or previous applications which were readily available; and telephone conversations and visits with the principal researchers.

Further documentation was then collected on the models which passed the initial screening and also on those which only marginally failed to meet the criteria described earlier. All of these models were examined more thoroughly in light of this additional information, and a few were subsequently dropped from further review. The remaining models, twenty-five in all, advanced to the second stage of the review process.

3.2 REVIEW BY THE PANEL

In the second stage of the process, the twenty-five urban modelling computer programs which had been chosen in the first stage were analyzed and evaluated by a selected review panel. This panel consisted of six persons experienced in the development and use of urban models. Emphasis in the selection of panel members was towards users rather than developers in order to provide background and experience for judgements on the applicability of various techniques. The panel was assisted as necessary by staff members from the Urban Transportation Research Branch and from the IBI Group. A complete listing of the participants in the review meetings is given in Appendix D.

The twenty-five models were divided into five groups: Land Use Models, Transportation Planning Models, Traffic Assignment Models, Truck/Transit Models, and Evaluation Models - with five models in each group. These categories do not match the ones used in Appendix A; rather, they were chosen in order to obtain five balanced groups of models for the review

process. Every participant in the review process was sent comprehensive documentation on all of the models in each of two different groups. In addition, each participant received short descriptions of the functions and techniques of all twenty-five models.

The panel members were asked to review the documentation which had been sent to them and to perform a preliminary evaluation of all of the models in the two groups for which they had received comprehensive information.

After the panel members had been given the opportunity to perform their initial evaluations of the models, a meeting was held at the IBI offices in Toronto to complete the second stage of the review process. The main objectives of the meeting were as follows:

- to determine what were the most important criteria to use in evaluating the models which had advanced from the first stage of the review process;
- to identify which of the twenty-five models met the above criteria in a convincing fashion;
- to decide upon what the future direction of the project should be.

A concensus was easily reached on what criteria should be used in evaluating the models. The panel members decided that the selected models should be:

- practical and innovative: the model should be geared to real life applications, should have reasonable data requirements, provide useful output and be relatively easy to use. The model should also represent a clear advance in urban modelling techniques and should not simply be a slight modification of existing techniques.

- theoretically sound: the model should have a strong theoretical base. Any assumptions that were used to develop the model theory should be consistent with accepted urban modelling practice.
- structurally practical: the model computer program should be a good representation of the model theory. The programming should also facilitate the use of the model.
- generally applicable: the model should be applicable to problems in urban areas across Canada. The theory and structure of the model should be transferable.
- sufficiently well developed: the model should, presently or in the near future, be in an operational state.

On the basis of the above criteria, the panel members selected roughly half of the twenty-five models.

Although there was general agreement on most of the selections, it was felt that the inclusion or exclusion of several of the models depended upon what the final objective of the project was to be. As stated earlier, the original aim of the project was "to provide a clear understanding of what work currently exists in Canada in a final product form and to use the best of that work as a basis upon which and around which to build future projects." Since the UTRB was scheduled to terminate operations shortly after the completion of the project, it was necessary to modify the latter part of the original aim. The panel members decided that instead of using the "best" models as the basis for future work of the UTRB, standard descriptions should be assembled for each of the selected "best" models and that these descriptions should be disseminated to model users and developers across Canada. In addition, the panel members agreed that standard descriptions should also be assembled for some of the existing, established Canadian urban modelling programs and packages. This information would be disseminated along with the description of the recently developed models.

The selected models were considered again in light of the new direction of the project and eleven of them were chosen to form the group of "recently developed" models, while two others were included with the established models. Standard descriptions for the former group are contained in Appendix B, and for the latter group in Appendix C.

3.3 MODELS SELECTED

The "recently developed" urban modelling techniques which were selected by the panel are listed below:

1. DEMTEC: Demande de Transport en Commun
   Marc Gaudry, Universite de Montreal

2. Transit Demand Model
   John Shortreed, University of Waterloo

3. Transportation Planning Model for Detailed Traffic Analysis
   Frank Navin et al, Univ. of British Columbia

4. CORQ: A Corridor Traffic Modelling Technique
   Sam Yagar, University of Waterloo
   CORCON: A Freeway Corridor Assignment and Control Model
   Brian Allen and Said Easa, McMaster University

5. EMME: An equilibrium Based Two-Mode Urban Transportation Planning Method
   Michel Florian et al, Universite de Montreal

6. Dynamic Urban Systems Model for the Toronto Region
   B.G. Hutchinson & G.M. Said, University of Waterloo

7. METRANS: An Interactive Transportation/Land Use Gaming Model for Metropolitan Toronto
   W.C. Found, York University
   R.G. Rice, University of Toronto

8. Truck Routes and Terminal Consolidation Model
   Norman Allyn, Swan Wooster Engineering, Vancouver

9. MICRO Model - URBGDS Model Package
   N.D. Lea and Associates, Oakville

10. Municipal Financial Impact Model
    Harvey Kriss and Associates, Toronto

11. Multi-Objective Dynamic Program
    M.A. Sargious, University of Calgary
    J.J. Salinas, Carleton University

The group of established Canadian models or packages for which descriptions were prepared includes the following:

1. Waterloo Land Use Transport Model
   B.G. Hutchinson, University of Waterloo

2. EMPIRIC Growth Allocation Model
   N.A. Irwin, IBI Group, Toronto

3. IBIMOD, A Comprehensive Traffic Prediction Model
   L.S. Sims, R.A. McNally, IBI Group, Toronto

4. Acres' STAP 2: Simplified Travel Analysis Procedures, Version 2
   David Crowley, Acres Consulting Services, Toronto

5. Ministry of Transportation and Communications, Ontario, System Programs

3.4 STANDARD DESCRIPTION

The type of standard description which was assembled for all of the models in the two groups is outlined below. The specific headings and subheadings that have been used for the description are given, along with brief outlines of the typical contents of each section.

1. TITLE:

The title of the model or technique as given by the principal researcher;

2. PRINCIPAL RESEARCHER:

The name, address and telephone number of the principal researcher. The principal researcher is the person to whom enquiries about the model should be directed.

3. AVAILABILITY:

Is an operational version of the model available? If so, from where and at what cost? Is a user's manual or other documentation available?

4. MODEL DESCRIPTION:

4.1 Summary Description:

The type of model (land use,travel demand, traffic assignment, etc.) and when it was developed. Brief descriptions are given of the basic function of the model, i.e. what type of problems does it solve, and the basic technique (simulation, optimization, etc.). The degree of sophistication required to use the model is also discussed as well as the present status of the model.

4.2 Inputs Required:

The inputs required by the model are listed by the following categories: historical data - either cross-sectional or time-series; environmental assumptions - information on exogenous variables such as future population, growth rates, employment, etc.; policy variables - those inputs which differentiate model runs and over which the user has some control; and model parameters - parameter values can be given, assumed or obtained by calibration.

4.3 Model Calibration:

If the model must be calibrated, the required inputs are listed, the calibration technique is described, e.g. maximum likelihood, regression, optimization, etc., and the outputs of the calibration process are given.

4.4 Model Process

The process which is used to determine the model output from the given input is described in terms of the model structure and any assumptions which are made. A flowchart is included if available.

4.5 Model Output:

The output provided by the model after it is calibrated is defined in detail.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements:

The computer system requirements of the model are given, including the size and type of the system, special hardware requirements and, when available, estimates of the CPU time for a typical run. In addition broad estimates of the costs of running the model are given.

5.2 Time and Staff Requirements:

The time and staff requirements for data collection, model calibration and testing, and model use are described in general terms. The requirements for the evaluation of the model output and the need for outside help are also given.

6. APPLICATIONS

Any previous applications of the model, illustrative, research, or practical, are listed.

7. BIBLIOGRAPHY:

A list of reports, papers, and other publications which relate directly to the model is given.

While the descriptions of the models in Appendices B and C are standard in terms of structure, the detail of the descriptions vary to some extent from one model to the next. This is the result of two main factors. Firstly, the models operate at different levels of complexity, and secondly, the documentation available for each model varied both in quantity and quality. Since the main function of this documentation is to provide standard information about a number of Canadian urban modelling computer programs and is not to compare the relative performance of the models, this variability in the detail of the descriptions should not detract unduly from its usefulness.

We believe that the simple availability of the information in this report will be of considerable service to workers in this field.

3.5 SEMINARS

In addition to providing this report, seminars were held in four cities (Toronto, Winnipeg, Edmonton and Vancouver) to discuss the results of this project. For each of these seminars, a person active in the field of

urban modelling was asked to invite interested participants to hear the results of this project and to discuss methods of proceeding on.

Over 150 participants from public agencies, consultants and universities took part in these seminars. Discussions were held at all seminars to discuss alternative methods of solving the information flow problem. The opinions expressed were taken into account when the project team developed its recommendations on this subject, which are included in Chapter 5.

4. STUDY FINDINGS

The overall findings of the study are discussed in this chapter. These findings are primarily a supplement to the standard descriptions of the various urban modelling computer programs which form the bulk of the report. Included in the findings are brief discussions on:

- the results of the initial survey;
- the selected models, both recently developed and established, for which standard descriptions were prepared;
- the areas of interesting research which were identified by the review process, but in which the models were not sufficiently developed for selection;
- where gaps in urban modelling were found to exist and if those gaps can be filled by models from elsewhere.

4.1 RESULTS OF THE INITIAL SURVEY

All of the urban modelling techniques which were identified in the initial stage of the review process are listed in Appendix A. The numbers of models in each category are listed by type of researcher (university, public agency, or private organization) in Exhibit 3. As would be expected, Canadian universities were the primary source of models. Although public agencies and private organizations combined provided more models, the numbers are slightly misleading since several of the models listed under these two groups are modifications or applications of models developed in the United States.

The models identified in the initial survey came from all parts of Canada. Roughly half of the models were developed in Ontario, while the remainder were equally distributed across other parts of the country.

EXHIBIT 3

MODELS IDENTIFIED IN SURVEY BY CATEGORY

CATEGORY	TYPE OF RESEARCHER: UNIVERSITY	PUBLIC AGENCY	PRIVATE ORGANIZATION	TOTAL
LAND USE MODELS	6	6	3	15
TRAVEL DEMAND MODELS	4	2	0	6
MODAL SPLIT MODELS	2	3	0	5
TRAFFIC ASSIGNMENT MODELS	8	3	0	11
COMPREHENSIVE TRANSPORTATION MODELS	4	5	5	14
OPERATIONS RELATED MODELS	3	1	1	5
URBAN GOODS MOVEMENT MODELS	0	1	3	4
EVALUATION MODELS	2	2	1	5
OTHER MODELS	1	1	1	3
TOTAL	30	24	14	68

The types of models which were identified also covered a broad range of subject areas. Virtually all aspects of urban modelling were represented by at least one or two models. However, most of the models were from the 'Land Use', 'Traffic Assignment', or 'Comprehensive Transportation Models' categories. These types of models are often major components in the development of land use/transportation plans for urban areas and would typically see more use than models from the other categories.

Although the listing of urban modelling computer programs contained in Appendix A may be incomplete, we feel that most of the recent significant developments in Canadian urban modelling have been included.

4.2 SELECTED URBAN MODELLING TECHNIQUES

In Chapter 3 of this report the 11 recently developed urban modelling computer programs which were selected by the review panel are named, and standard descriptions of these models are given in Appendix B. This section contains a brief discussion of the selected models in terms of their possible applications and the compatability among them.

Comprehensive Planning Models

Although no recently developed land use activity allocation models were selected by the review panel, the two comprehensive planning models which were chosen, the Urban Systems Model and METRANS, have land use allocation components. The former model is composed of ten sub-models most of which deal with land use characteristics such as the spatial distribution of households, employment and land use categories. The transport sub-model of the Urban Systems Model uses the EMME equilibrium traffic assignment model which

was also selected by the review panel. Obviously there is a high degree of compatibility between these two models, although the EMME model can be used independently while the Urban Systems Model requires the use of EMME.

The other comprehensive transportation planning model, METRANS, is actually a gaming model which can be used to demonstrate the transportation planning process to transportation and planning professionals and students and also to non-professionals who are interested in this area. METRANS is an interactive model written in APL and therefore it would be difficult to integrate it into a package with the other selected models since they are written in other programming languages. It may be possible to link METRANS with STAP 2, one of the 'established' models which is also written in APL.

Traffic Assignment Models

The four traffic assignment models which were selected each involve different scales of application. The 'Transportation Planning Model for Detailed Traffic Analysis' is a stochastic traffic assignment procedure which models the movement of automobiles, transit vehicles and pedestrians in small areas, such as the CBD. The CORQ model and the CORCON model (which is a modified version of CORQ) are freeway traffic modelling techniques. These models assign time-varying origin-destination demands to a specific network and predict flows and queues on the freeway and major adjacent arterials in that network. The fourth model, EMME, combines a demand model (which may be a direct demand model or an O-D table coupled with a modal split function) with an equilibrium type car trip assignment and a transit assignment method. EMME determines equilibrium demands, flows and service levels on both

the road and transit networks of a city by considering the variable demand between the two modes as well as the interaction on the road infrastructure between private cars and transit vehicles.

Since the CORQ and CORCON models are dynamic traffic assignment models which require time-varying origin-destination demands as inputs, it is unlikely that they could be used directly in conjunction with the other two models. On the other hand, some of the output of the EMME model could conceivably be used as input into the 'Transportation Planning Model for Detailed Traffic Analyis'. The former would be used to estimate the road and transit flows on the major links into the CBD, while the latter would distribute these flows over a more detailed network within the CBD.

Transit Demand Models

Two recently developed transit demand models were selected by the review panel. The DEMTEC model is basically a demand equation which is used to explain the aggregate monthly demand for public transit in terms of the time series values of a number of independent variables such as the prices of public and private transportation, the price levels of non-transportation goods, service characteristics of competing modes and income and socio-economic variables. The 'Transit Demand Model' is a trip rate and elasticity type model which is oriented to short range operations planning and operations on a route by route basis. The basic function of the model is to estimate the number of passengers boarding and alighting over different sections of a transit route from service parameters and socio-demographic data relating to the immediate vicinity of the route.

These two models are at opposite ends of the spectrum of demand estimation models. The DEMTEC model deals with the aggregate monthly demand for a transit system as a whole, while the 'Transit Demand Model' estimates the hourly and daily demands on a single transit route. The models are complementary in that the areas which they address do not overlap, but due to different input requirements - time series data for DEMTEC, cross-sectional data for the 'Transit Demand Model' - the models are not compatible at the operational level.

Urban Goods Movement Models

Two urban goods movement models were also selected by the review panel. The 'Truck Routes and Terminal Consolidation Model', as indicated by the title, rationalizes two components of truck fleet operations, namely the consolidation of (1) truck routes, and (2) terminal operations. The overall objective of the model is to generate the most efficient, i.e. least costly, truck operating network. The MICRO model of the URBGDS Modelling package is a queueing model, written in the GPSS simulation language. The basic function of the MICRO model is to simulate the goods transfer operations at a single endpoint. An endpoint is a particular geographical location (usually a building) in an urban area where goods are picked up and/or delivered.

As in the case of the two transit demand models, these two models are complementary. However, they are written in different programming languages. The 'Consolidation Model' is written in Fortran and interfaced with a simpler language called FLECS, while MICRO is written in GPSS.

Evaluation Models

The two evaluation models which were selected by the review panel are very different in terms of function. The 'Municipal Financial Impact Model' was designed to evaluate the financial impacts, particularly the effect on mill rates, of such things as: major proposals by developers, changes in the level of particular municipal services, or changes in the municipality's policies on the financing of capital expenditures. The 'Multi-Objective Dynamic Program' provides an evaluative procedure for the optimal selection of large-scale project components associated with, for example, airports or urban transportation systems. It evaluates the components according to their economic viability and then reranks them according to their effectiveness in satisfying the set of objectives selected for the project.

The first model is completely quantitative, and deals primarily with financial variables. The second model uses a mixture of quantitative and qualitative measures, although the latter are assigned numerical values. The output of the 'Financial Impact' model could be used as input into the 'Multi-Objective Dynamic Program'. The output from many of the other selected models could indirectly provide input for both of these evaluation techniques.

4.3 ESTABLISHED MODELS

The selected established Canadian models and modelling packages are listed in Section 3 of this report and standard descriptions on these models are given in Appendix C. All of these models were developed by Canadians and have either had a number of applications in various urban areas or are based on standard techniques which have been used often in other urban models.

Land Use Models

Two of these models are land use activity allocation models. The "Waterloo Land Use-Transport Model" is a derivative of the Lowry model which allows activity allocations and transport flows to be estimated simultaneously. The basic function of the model is to estimate the demands for household opportunities by income group at each work place location (traffic zone) and then to allocate the demands to compatible housing opportunities. The EMPIRIC model is designed to allocate projected regional population, employment, and other land-use activity growth among the smaller sub-regions of districts. The model consists mathematically of a set of simultaneous linear equations, relating changes over time in the distribution of regional population and employment to their original distribution in some base year, their region-wide growth over a series of specified forecast periods, and the predicted effects of selected, exogenously specified planning policies.

Although the two models perform basically the same function, they use different techniques to allocate activities. Both techniques, a Lowry-type demand equation in the Waterloo model and simultaneous linear equations calibrated by regression in the EMPIRIC model, have been applied in a number of urban areas.

Since both models perform the same function, one would generally only apply one of them in a specific urban area. The output of the models could be used as input into the trip generation phase of the standard transportation planning process. The degree of compatibility which could be achieved at the programming level would vary from one model to another.

Strategic Transportation Planning Models

The IBIMOD and STAP 2 models, as well as one of the system packages available from the Ministry of Transportation and Communications (MTC), Ontario (System 033) are strategic transportation planning models. All three models incorporate the standard four phases of the transportation planning process: trip generation; trip distribution; modal split; and traffic assignment. The models are relatively inexpensive to run, and two of them, IBIMOD and STAP 2, are generally easier to use than most comprehensive transportation planning models.

The STAP 2 model is an interactive program written in APL, as is METRANS; IBIMOD is written in Fortran. The 'System 033' computer programs are completely compatible with the programs in the more complex 'Transportation Planning System' (TPS) of the MTC. Since the input requirements and the outputs of both System 033 and IBIMOD are relatively standard, program compatibility could be achieved with many other urban modelling techniques. This is especially true of IBIMOD which can be easily modified to respond to specified needs.

Comprehensive Transportation Planning Packages

Two other programming packages that are available from the Ontario MTC are the 'Transportation Planning System' (TPS) and the 'Priority Planning' package (System 037). The Transportation Planning System includes programs for data bank, road/transit networks, trip generation, trip distribution, modal split and table manipulation. The programs were designed for large urban area studies, can handle studies with up to 1500 traffic zones, and will accommodate a transit network with up to five separate modes of transit.

System 037, Priority Planning, is used by the MTC to record, evaluate and rank road construction projects on the basis of economic need and constrained by the available budget.

As stated earlier, the programs of the TPS and of System 033 are completely compatible. System 037 is aimed primarily at evaluating highway improvements and is therefore not directly compatible with the other packages, although all of the packages are run on the same computer facility.

4.4 AREAS OF INTERESTING RESEARCH

Through the initial survey phase of the review process, a number of models were identified which were either in developmental stages or were fully operational but not documented. Because of this, the review panel was unable to evaluate or select them. Even if the models had been selected by the panel, standard documentation could not have been readily assembled on them. In this section some of these models will be briefly described and the principal researchers involved in their development will be named.

Land Use Models

In the area of land use models Prof. Frank Saccomanno of the Department of Civil Engineering of the University of Waterloo has developed a wage-based model of residential site value transfer. This research was performed while Saccomanno was a doctoral student at the University of Toronto. Site value transfer represents the process, whereby commuting cost savings are transferred into "differential rents" on more advantageously located sites. These periodic rent payments are then capitalized into a site value increment of total housing price at a given point in time. The model employs an iterative algorithm that interrelates commuting cost savings,

site value transfer, land use development, population-employment allocation and the transportation planning process. The model is documented in a Ph.D. thesis entitled "A Wage-Based Model of Residential Site Value Transfer" which was submitted by Prof. Saccomanno to the University of Toronto in 1978.

Travel Demand

Some very interesting research is also being performed in the area of modal split or market share models. Models based on generalized cost difference using the logistic functional form and aggregate data have been applied in Edmonton by the City's Transportation Planning Branch and in Winnipeg as part of the 'EMME' project.

Prof. Marc Gaudry of the Centre de Recherche sur les Transports of the Universite de Montreal has developed a modified version of the logit function called the 'Dogit Model'. The model is flexible enough to permit the choice among specific pairs of alternatives to be consistent with the independence from irrelevant alternatives axiom, as in a logit model, but it simultaneously allows the choice among other pairs not to be. Dogit parameters add an "income effect" to the "substitution effect" already built into the logit model; alternatively, they allow for the joint presence of compulsive and discretionary elements in consumer behavior, or for the identification of captive markets. Gaudry has tested the model with aggregate time series and cross-sectional data, but the results have been inconclusive. The model is also being tested by others using disaggregate data. Gaudry has published a number of papers on the model and these are available from the Centre de Recherche sur les Transports of the Universite de Montreal (Publications #82, #94, and #107).

Research on applications of the multinomial logit model using dissaggregate data has been done by Prof. Richard Westin of the University of Toronto (presently with the World Bank in Washington D.C.). Recently Westin and others have applied the model in a study of the modal choice of travellers going to the bus, rail and air terminals in Ottawa. Westin has also done research on the transferability of disaggregate mode choice models and on the problems of aggregating the modal splits obtained from disaggregate models. (Westin, R.B., "Predictions from Binary Choice Models", Journal of Econometrics 2, 1-16, North Holland Publishing Company, 1974; Watson, P.L. and Westin, R.B., "Transferability of Disaggregate Mode Choice Models", Regional Science and Urban Economics 5, 227-249, North Holland Publishing Company, 1975.)

Assignment Models

While a number of recently developed traffic assignment models were selected by the review panel, there are a few other assignment models worth noting. In Edmonton, Terry Clement and others in the City's Transportation Planning Branch have developed a macro level assignment model, and are also in the process of developing a micro level model. The former is an incremental traffic assignment model which employs dynamic travel time adjusment. Basically the model uses Dial's probabilistic multipath program (Dial, R.B., "A Probabilistic Multipath Traffic Assignment Model Which Obviates Path Enumeration", Transportation Research, Vol. 5, 1972) modified so that travel time on each link is updated each time additional trips are assigned to the link. The model has been used extensively in Edmonton, but the only documentation available on the model is user documentation specific to Edmonton.

The micro-assignment model which is currently under development will allow the downtown street system to be studied in greater detail. The model will assign a trip table produced by the macro-assignment model to a detailed downtown network. It will take into account the link capacity, signal timings, signal progressions and other factors when calculating link travel times during its incremental loading process. The resulting loaded network is input to the 'TRANSYT' model (developed in Britain by the Transport and Road Research Laboratory) which optimises the signal settings for this pattern of traffic flow. After updating the network with the new signal settings the micro-assignment model is used again. This procedure is repeated until equilibrium is reached.

In other work in the traffic assignment area, a Monte Carlo Assignment technique was developed by W. Copeland, based on earlier work by Karl Dieter and extended by L. K. Saith and A. Ebrahim in research performed at the University of Toronto. This assignment technique is based on the principle of incremental loading; i.e., traffic is assigned to the originally empty network in successive steps, while the travel time for each link is constantly updated. In each step, the shortest routes are calculated anew, on the basis of the travel times then prevailing. This leads to a gradual loading of the system preventing excessive link loads on any given path, thus making iterative adjustments unnecessary. In each step a constant increment of traffic is assigned only from one generator-attractor pair. The generators and attractors are selected at random in proportion to their generating and absorbing intensities. The random selection process is modified in such a way that the distribution formula is taken care of without specific calculations. Thus, a specific distribution based on updated link travel times, is carried out with each step. Copeland incorporated this technique into a

standard traffic prediction model, while Ebrahim modified the technique and added a disaggregate logit modal split model. A technique developed by Richard Westin of the University of Toronto was used to aggregate the modal splits. (Copeland, W. J., "A Traffic Prediction Model Utilizing Monte Carlo Assignment", an unpublished M.A.Sc. Thesis, University of Toronto, April, 1968; Saith, L.K., "A Comparative Analysis of Trip Distribution and Assignment Procedures", an unpublished Ph.D. Thesis, University of Toronto, 1969; Ebrahim, A.A.N., "Monte Carlo Trip Distribution and Assignment Model with Logit Modal Split Model", an unpublished M.Eng. Thesis, University of Toronto, 1976.)

Traffic Signal Optimization

Some developmental work is also being done in the area of traffic signal setting optimization. Prof. Brian Allen of McMaster University in Hamilton has prepared a computer program called 'SSTOP' (Signal System Optimization Program). The program was originally developed as an on-line traffic signal optimization program during the Improved Operation of Urban Transportation Systems (IOUTS) study conducted by the Metropolitan Toronto Roads and Traffic Department under contract to the Transportation Development Agency and the Ontario MTC. Appropriate modifications were undertaken to convert this real-time program into an off-line analysis tool for establishing optimal settings for fixed time time-of-day systems. The SSTOP package is designed to compute optimal signal timing parameters (cycle lengths, offsets and splits) off-line, based upon a given set of input parameters. The model is presently being evaluated in three Canadian cities (Montreal, Quebec City, and Cambridge, Ontario) in studies sponsored by the Urban Transportation Research Branch.

Input-Output Models

In the area of urban economic models some interesting research has been done using input-output formulations. Prof. H. Craig Davis of the School of Community and Regional Planning at the University of British Columbia developed "An Urban Interindustry Input-Output Model". The model is based on Leontief's (1953) classical input-output formulation as adapted for a spatial subsystem of a national economy. Input-output analysis is a particular form of detailed quantitative economic analysis which focuses upon the interdependencies among the various sectors of the economy under study. It is a means by which one can trace the effects of a change in one sector of the economy upon all the other sectors. This form of economic analysis has been utilized by a large number of countries, and in recent years, the application of the analysis on a subnational scale has greatly proliferated. (Davis, H.C., "An Interindustry Study of the Metropolitan Vancouver Economy, Report No. 6, Urban Land Econmics, University of British Columbia.)

Another model which uses input-output formulation is the 'Micro-Economic Impact Model' developed by Prof. Tillo E. Kuhn of York University. The basic function of this model is to provide a framework for the analysis and interpretation of the economic impact of a given project. The model uses a combination of value-added contributions and input-output tables to determine the economic impact of the project by category. These categories may include wages (by classification of employee), interest, retained earnings, dividends, taxes, and rent. (Kuhn, T. E., "The Economic-Industrial Impact of Large Transport Projects", RTAC Annual Conference Proceedings, Vol. 6, 1975.)

Computer Animation

The final area of research which was identified was the application of computer-animated simulation models to transportation planning. Work in this area has been done by Prof. Ronald M. Baecker and others of the Computer Systems Research Group at the University of Toronto. In one study models of taxi dispatching systems and strategies were built. The implications of each strategy were portrayed by the production and playback of an animated movie which depicted the simulated system. Another study involved the modelling and display of passenger flow in a subway station. Using these techniques, the modeller can observe the system, modify the strategy, and immediately see the effects of the change. (Baecker, R. M. et al, "Computer-Animated Simulation Models: A Tool for Transportation Planning", Transportation Research Record 557, Mode Change Facilities, 1975.)

Without a doubt there are other urban models in various stages of development by Canadian researchers. The models which have been described above were selected in an attempt to present an overview of the areas of urban modelling which are currently being researched in Canada. Since many of these models are still being tested and validated, their inclusion in this report does not reflect a detailed evaluation of their theoretical and structural framework. Similarly, the exclusion of any other model does not represent a negative evaluation of its overall worth.

4.5 AREAS WHERE RESEARCH IS REQUIRED

The models which have been included in Appendices B and C of this report cover a broad range of areas in urban modelling. In addition, as was

outlined in the previous section, a number of other areas are presently being researched in Canada. Model users and developers should also be aware of the many urban modelling computer programs which are available from various agencies in the United States and other countries. The following three publications provide information on a large number of these models:

1. Sosslau, A.B., et al, Travel Estimation Procedures for Quick Response to Urban Policy Issues, National Cooperative Highway Research Program (NCHRP) Report 186, Transportation Research Board, Washington, 1978

2. Belloms, S.J. et al, Evaluating Options in Statewide Transportation Planning/Programming, NCHRP Report 179, Transportation Research Board, Washington, 1977

3. Peat, Marwick, Mitchell and Company, A Review of Operational Urban Transportation Models, prepared for United States Department of Transportation (DOT), Report No. DOT-TSC-496, April 1973.

Three major sources of some of the models contained in these publications are:

- Planning Methodology and Technical Support Division, Urban Mass Transportation Administration (UMTA) U.S. Department of Transportation

- Urban Planning Division, Federal Highway Administration (FHWA), U.S. Department of Transportation

- Transport and Road Research Laboratory (TRRL), Department of the Environment, United Kingdom

It is difficult to identify with certainty any areas of urban modelling where research is not currently being done in Canada. However, there are a number of areas where a greater effort seems to be required. The areas identified are discussed in the next chapter.

5. CONCLUSIONS OF THE STUDY TEAM

This chapter of the report represents the conclusions of the consultant study team rather than those of the client (the Urban Transportation Research Branch) or the members of the expert panel.

5.1 ACTIVITY IN THE URBAN MODELLING FIELD

As can be seen from this report, there is a considerable amount of activity in urban modelling across Canada. The areas of activity, however, are not uniform. There is more interest in certain areas than in others. This can be seen both in Exhibit 3, showing the distribution by category of the various models submitted through the survey mechanism and in the types of models selected for dissemination.

Modal split and assignment models are very well represented. Out of the 11 selected models, three can be included in this category, EMME by Michel Florian et al, CORQ/CORCON by Sam Yagar and Brian Allen and the Transportation Planning Model for Detailed Traffic Analyses by Frank Navin et al.

By comparison, there seems to be a lack of activity in the development of new trip generation and distribution techniques. Most of the models reviewed used linear regression equations or category analysis to calculate number of trip ends in particular zones and all either assumed an O/D matrix will be provided by the user or used a gravity model to obtain trip distributions. Perhaps the reason that these areas have not been further explored is the fact that the standard techniques

provide sufficiently good answers. However, experiences of the project team in the past have shown that there are limitations to these methods. For example, linear trip equations or category analysis formulations do not satisfactorily explain the variations in trip rates between areas or the mechanism by which trip rates by hour can change to reflect congestion. Similarly, the gravity model formulation of the distribution process is not always suitable. More general formulations of distribution patterns have been done theoretically, but few have been applied in practice either in Canada or abroad. One important exception to this is the work being done on intervening opportunity models being done at the University of Melbourne, Australia. Apparently the intervening opportunity model has been developed to a considerable extent and is now considered operational. It is suggested by the study team that trip generation and trip distribution would be fruitful areas for further work on the development of practicable and applicable models in Canadian urban areas.

It was also pointed out during the seminars that one of the greatest problems with predicting future trip distribution patterns is uncertainty regarding land use patterns. Residential land use activities were relatively easy to predict but employment location and type more difficult. In fact, some of the participants at the seminars pointed out that there is very little information on employment and land consumption in existing industrial areas. This lack of knowledge was seen as a gap which would have to be filled before more theoretical work was done.

The two truck models selected include one that evaluates the possibility of consolidation terminals and one that simulates operations within a single terminal. Both of these are very specific in terms of the problems

addressed. There seems to be a lack of more general models of goods movement. Perhaps this is a symptom of the lack of detailed information on goods movement generation and movement patterns in Canada but it definitely points to a gap in the techniques available for urban modelling. Several seminar participants recommended that greater attention be paid to collecting data on urban goods movement so that a firm basis could be provided for development of models and other analytical techniques to study the problems of urban goods movement.

Allocation models for land use activities are fairly well represented. There seems to have been a great deal of activity in this particular field both in the past and currently.

5.2 LACK OF DOCUMENTATION

It was observed during the course of this project that, in general, only two types of projects produced documented transferrable computer programs. These were programs developed in universities and other academic institutions and those developed under Transport Canada or other Federal Government sponsorship. With a few exceptions (the most notable being the packages and programs developed by the Ministry of Transportation and Communications, Ontario), other computer models that were developed by municipalities or consultants were not usually documented sufficiently to be put into the public domain. Municipalities and local planning agencies do use a wide variety of modelling techniques. For example, a report prepared by the Centre de Recherche sur les Transports of the Universite of Montreal for the Urban Transportation Research Branch in 1975 ("Survey and Inventory of Computer Based Urban Transportation Planning Techniques", Urban Transportation Research Branch, Transport Canada,

November 1975) showed a wide variation of techniques used from city to city. Many of these were developed locally, often with the assistance of consultants, but few were documented in a way such that their technique could be transferred from one municipality to another. It has also been noted in Chapter 4 that very interesting research in various fields is being done by such municipalities as Edmonton, Calgary and Vancouver. Based on past performance, it is not likely that municipal governments will be able to devote the resources to produce fully documented and fully developed computer programs that could be used in other cities; however, although in this particular case some of the Vancouver research is being done under contract by a university department which wishes to use the same techniques for application in other cities.

With the dissolution of the Urban Transportation Research Branch and the Ministry of State for Urban Affairs, there may be considerably fewer Federally sponsored research projects in this area. There seems to be little incentive, apart from academic recognition, for others to publish or document their programs sufficiently to put the programs into the public domain.

5.3 DISSEMINATION CHANNELS

The expert panel convened for this project decided that the documenting of a number of useful computer programs in this report would in itself be a desirable objective, so that workers in this field could be informed as to the availability of various types of programs. We believe that there will be a continuing need for just such an information transfer process to update this material in the years ahead. The considerable effort required in this project to determine activities in this field and to

critically compare various models and programs implies that, to be effective, considerable staff resources would be required.

At some of the seminars held as part of this project, it was suggested that perhaps the Roads and Transportation Association of Canada (RTAC) might take over this function. We believe that an RTAC Committee could perform this function if it had the necessary staff resources, perhaps supplied by a grant from Transport Canada or some consortium of Federal and Provincial agencies. We do not believe that a continuing responsibility of this sort could be undertaken effectively by RTAC strictly through the use of volunteer committees. Another suggestion was that a university research centre could perform this function if it had similar assistance from Transport Canada or others. Other suggestions as possible agencies which could coordinate activities were the Canadian Institute of Transportation Engineers or some similar professional organization or a new organization to be set up by the Provincial and Federal Governments together. It was agreed at all the seminars that, with their greater responsibility and involvement in transportation planning and operations, Provincial Governments must become involved. It was pointed out that in the United States some research and administrative staff for various projects is supplied by the Council of Governors. This contribution is being made by the individual States. A similar organization could be developed in Canada. However, RTAC already has representation from both Provincial and Federal Governments and it may be possible to use the present RTAC organization to carry out such a function. RTAC has already been the vehicle through which cooperative research programs have been financed and administered.

We therefore recommend that Transport Canada should consider, in consultation with the Provinces and the Technical Committee of RTAC, various avenues for continuing this work and updating it on a regular basis. We believe that this function could be done at reasonable cost (possibly $10-$20,000 per year) and would help fill the needs of many potential users, especially those in municipal governments. If it is found that RTAC is not the most appropriate organization, we would recommend that a Federal-Provincial coordinating body be set up and funded to perform this function. Perhaps the present Intergovernmental Committee on Urban and Regional Research might be the basis on which to build this function. The actual staff could be provided by secondment from one of the member governments, by contract with consultants, or by contract with a university research centre.

There is a second need that was determined, that is to make various types of programs compatible, both in format and in formulation. To investigate this need was one of the original objectives of this project. While achieving such compatibility is still thought to be a desirable objective, it will require a continuing commitment of resources at a level which may not be immediately forthcoming in light of the Federal Government's decision to terminate both the Urban Transportation Research Branch and the Ministry of State for Urban Affairs. We suggest that this also be considered, possibly as a longer term program by Transport Canada and the Provinces, again possibly through the good offices of RTAC.

MODELS LISTED
RESPONSE TO SURVEY
CLASSIFIED BY CATEGORY

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APPENDIX A

MODELS LISTED BY
RESPONSE TO SURVEY
CLASSIFIED BY CATEGORY

LAND USE MODELS

RESEARCHER & ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
B.G. Hutchinson, Civil Engineering University of Waterloo	A derivative of the Lowry model Allows activity allocations & transport flows to be estimated simultaneously (1973)	report on application, small user's manual	numerous practical applications
Richard J. Arnott James G. MacKinnon Economics, Queen's University	Static, general equilibrium models of the urban economy solved by use of a fixed point algorithm (1974-1977)	papers on underlying theory and structure of model	illustrative applications only
John M. Hartwick Economics Queen's University	Linear programming model of urban transportation and land use, space incorporated in discrete units (1974)	papers on underlying theorgy and structure of model	illustrative applications only
Greg Schwann, Steve Jacobs, Planning Department, City of Regina	Housing demand model calibrated by linear regression with demographic and economic variables (1978)	paper on model structure and on applications	practical applications in Regina
Steve Jacobs, Planning Department City of Regina	Allocation model Distributes total population and housing projections of a city to its sub areas using a number of equations calibrated by linear regression (1977)	papers on model structure and on applications	practical applications in Winnipeg and Regina

RESEARCHER & ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
Peter George GVRD Vancouver, B.C.	1. Allocation model Distributes residential growth to sub-areas according to a set of regional residential settlement criteria (1974) 2. Employment forecast & spatial distribution Matches land supply & characteristics with land requirements of employment sectors (1974)	source listing only source listing and paper describing model structure and application	Practical applications in the Greater Vancouver Regional District
Normand Lucas, Project Speciaux, Ministere des Transport du Quebec	Allocation of use & infilling of small zones based on rate of growth of population and employment(1974-1975), modified version of a model developed at the University of Chicago	comprehensive user's manual in French	practical application in the south shore communities of Montreal
Raymond Aaron Peat, Marwick and Partners Toronto, Ontario	Urban Land Development Costing Model Inputs time series of land costs & revenues calculates internal rate of return (1977)	sufficient to use program	practical applications in various cities across Canada
Peter Sandor Richard Allingham, Peat, Marwick and Partners, Toronto, Ontario	Impact of Zoning Controls Financial simulation of residential/commercial consturction, major policy variable input: building density (1975)	documentation available from Peat, Marwick and Partners	practical application in the City of Toronto
Neal A. Irwin, Peat, Marwick and Partners IBI Group Toronto	EMPIRIC Simultaneous linear equations to allocate population, employment, land-use growth to sub-area Consists of sub-models which may be claimed or used independently	numerous papers and articles on the model structure and its applications	practical applications

RESEARCHER & ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
Dale O. Petersen Planning Department City of Edmonton	Allocation of population & employment, a variation of the Voorhees Urban Systems Model. Sub-model A (1977)	limited documentation	practical application planned for the City of Edmonton
O. Bowen etal Civil Engineering University of Calgary	Garin-Lowry Model - formulation of a Garin-Lowry Model for Calgary (1972)	report on application	research application in Calgary
R.W. McCabe Department of Urban and Regional Planning University of Toronto	WILSON: Calculates interzonal sales from zonal retail data, using Wilson's entropy maximizing model	comprehensive documentation	Case studies in Oshawa and Belleville
F. Saccomanno Civil Engineering University of Waterloo	A wage-based model of residential site value transfer, with an associated land development componenet (1975-1978)	thesis describing model theory and structure	research application using Toronto data

TRAVEL DEMAND MODELS

RESEARCHER AND ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
J.F. Morrall Civil Engineering University of Calgary	Proportionate trip generation and distribution model for small towns (1973-1974)	a paper on the model, documented computer program	several practical applications in small Canadian Towns
Marc Gaudry Centre de recherche sur les transports University de Montreal	DEMTEC Transit ridership demand model (1970-75)	User's Manual	practical applications in Montreal and forthcoming in Toronto
T.O. Clement Transportation Planning City of Edmonton	1. Work trip generation models which predict choice/captive production/attraction trip ends on a small area basis (1976)	Basic concept described in unpublished thesis by principal researcher	Practical applications in Edmonton
	2. A fully constrained gravity type distribution model which distributes choice trips and captive trips seperately (1975)	user documentation built into program	practical applications in Edmonton
B.C. Hutchinson Civil Engineering University of Waterloo	Gravity model for work trips developed from 1971 Census data on the trip to work (1977-78)	report on model	research applications using data from Ontario census metropolitan areas
J.H. Shortreed Civil Engineering University of Waterloo	Transit Demand Model, predicts ridership on individual transit routes by route section from service parameters and socio demographic data (1977)	report on model structure and calibration	practical and research applications in Kitchener-Waterloo, Cambridge and Toronto

ROAD AND TRANSIT ASSIGNMENT MODELS

RESEARCHER & ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
F. Navin, G. Brown, J. Hall, Civil Engineering University of British Columbia	Stochastic assignment of vehicle traffic to detailed street networks Graphical results in form for traffic engineers (1975-1978)	paper on model structure and data entry manual	practical applications in Vancouver, and Municipality of Richmond
Sam Yagar, Civil Engineering University of Waterloo	CORQ Corridor traffic modelling technique Assign O-D's to network & predicts flows & queues (1970-1973)	report and papers on model structure and application	research applications in Ottawa and San Francisco
Robert Chapleau, Centre de recherche sur les transports University de Montreal	TRANSCOM Assigns riders onto a public transit network given O.D. data (1974)	numerous papers on model structure	practical application in Montreal
Sang Nguyen, Centre de recherche sur les transports University de Montreal	TRAFFIC An equilibrium traffic assignment program (1974)	numerous papers on model theory and structure	several practical applications both in Canada and overseas
M. Florian et al, Centre de recherche sur les transports University de Montreal	EMME Bimodal assignment and modal split model (encorporates TRANSCOM & TRAFFIC as sub programs) (1976-1978)	numerous papers on model structure and application user's manual to be available in 1979	practical application in Winnipeg

RESEARCHER & ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
Dr. E. Hauer Department of Civil Engineering University of Toronto	Road Runner Freeway Model - Analyzes urban freeway links using the hydrodynamic theory of traffic flow (1975-1978)	Final report - Ministry of Transportation and Communications, Ontario	research applications using Toronto data
W.J. Copeland L.Saith, A.Ebrahim Department of Civil Engineering University of Toronto	Monte Carlo Trip Distribution and Assignment Program - assigns auto trips to a network by iterative incremental loading (1968, 1976)	documented in Master's Thesis by researchers	research applications using Toronto data
Brian L.Allen Department of Civil Engineering McMaster University	CORCON - A freeway corridor assignment and control model. Modification of Yager's CORQ model (1974-76)	papers documenting model structure and application	practical application in Mississauga
T.O. Clement Transportation Planning City of Edmonton	1. An incremental traffic assignment model employing dynamic travel time adjustment (1976) 2. A micro-assignment model, which is to be used to assign trips to a detailed downtown network (under development)	user documentation specific to Edmonton no documentation presently available	practical applications in Edmonton practical applications planned in Edmonton
A.J. Ugge Ministry of Transportation and Communications, Ontario	Model for Urban Transit Systems Planning and Analysis - determines travel times, modal split and trip assignment on a transit network which is represented as a uniform grid	report on model structure and use, program documentation available from researcher	researcher and illustrative applications using several networks

MODAL SPLIT MODELS

RESEARCHER AND ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
F.A. Curtis Urban & Regional Planning Queen's University, Kingston, Ontario	Disaggregate demand model (logit form) transfer of a model calibrated in Washington D.C. to applications in Boston (1977)	documented computer program	application in Boston
Marc Gaudry Centre de recherche sur les transports University de Montreal	DOGIT MODEL - market share or modal split model - modification of miltinomial logit (1977)	numerous acedemic papers	research applications using Montreal data
T.O. Clement Transportation Planning City of Edmonton	Choice modal split model based on generalized cost difference using logistic functional form (1975)	working notes and considerable documentation within program	practical applications in Edmonton
A.J. Ugge Ministry of Transportation and Communications, Ontario	Disaggretate logit and probit modal split models developed using program written by J. Cragg of University of British Columbia (1976)	report on development of models	research applications using Tôronto data
C. Disloges F. Major Ministere des Transport	Ulogit - a U.T.P.S. module which performs modal split on the basis of generalized costs.	report on model structure and use in French is available from reseachers	practical application in the South Shore communities of Montreal

COMPREHENSIVE TRANSPORTATION MODELS OR PACKAGES

RESEARCHER & ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
Don Hill, B. Helm Peat, Marwick and Partners, Toronto, Ontario	Traffic Prediction Model including generation, distribution, modal split and assignment modules (1964-65)	documentation available from Peat, Marwick and Partners	practical applications in Toronto, Merseyside
David Crowley Acres Consulting Services Ltd. Toronto, Ontario	Acres STAP 2 - analyses land use/transport alternatives; interactive program written in APL (Advanced Programming Language) (1976-1977)	Haldimand-Norfolk Transportation Study Phase I report	practical applications in Haldimand-Norfolk
A.K. Wong Regional Municipality of Halton, Ministry of Transportation and Communication, Ontario	STP: Simplified Transportation Planning; generation, distribution modal split, assignment - calibrated to screenline volumes (1975-1976)	User's Manual available from Ministry of Transportation and Communications of Ontario	practical applications in Halton Region
City of Calgary	Modification of Voorhee's TRIPS Package - generation, distribution, modal split, assignment modules (1964-1971 updated)	User's Manual Technical reports	practical applications in Calgary
L. Shallal, Regional Municipality of Ottawa-Carleton	UTPS: conventional models, plus disaggregate modal split, urban goods modelling techniques being developed	User's manuals for computer programs & draft reports on models under development	practical applications in RMOC/CRO Regions
Wilbur Smith and Assoc. Canadian British Consultants Ltd. Halifax, N.S.	An adaptation of the U.S. Bureau of Public Roads Planning Model (1972)	User's Manual	practical applications in Halifax-Dartmouth, N.S

COMPREHENSIVE TRANSPORTATION MODELS OR PACKAGES

RESEARCHER AND ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
B.G. Hutchinson Civil Engineering University of Waterloo	Dynamic urban systems model - allocates 7 household types and 5 employment types - calculates transportation flows (1978 -)	documented computer program	application in Boston
W.C. Found, R.G. Rice University of Toronto/York Joint Program in Transportation	METRANS - an interactive simulation game (APL) for operational investment decisions of road and transit networks in Toronto	progress report and user's manual	research applications using Toronto data
Giulio Maffini Development Planning Associates Ltd. Halifax, N.S.	Simplex Land Use Transport Model estimates the effects of implementing various urban form scenarios and transit usage profiles	model summary	practical application in Halifax, Nova Scotia
Michael A. Goldberg Faculty of Commerce University of British Columbia	Simulation Modelling of Urban Land Uses and Transportation - four principal sub-models: housing and other land use models; a regional economic impact model; a regional population model	comprehensive documentation including papers on model structure & user's manuals	practical and research applications in Greater Vancouver Regional District
C. Desloges, F. Major, J.P. Primeau, Ministere des Transports du Quebec	UTPS modelling package	program documentation in French	practical applications in the South Shore communities of Montreal
L.Sims, R.A.McNally IBI Group Toronto, Ontario	IBIMOD- strategic transportation planning package, including generation, distribution, modal split and assignment	user's manual and other reports on model application	practical applications in a number of cities in Ontario

RESEARCH AND ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
Ministry of Transportation and Communications	System No. — Title 019 - Municipal Planning Data 021 - Origin/Destination Survey Processing 023 - Traffic Data Bank 024 - Public Transit Planning 025 - Road Transportation Planning 033 - Simplified Transportation Planning	extensive documentation available from Ministry of Transportation and Communications	numerous practical applications in both Ontario and other provinces of Canada

OPERATIONS RELATED MODEL

RESEARCHER & ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
A.S. Berg, Computer Methods of Canada, Toronto	Bus route simulation to optimize stop spacing (1977-78)	some documentation from researcher	illustrative applications
Ezra Hauer, Ron Baekker, Paul Bunt University of Toronto	Computer simulation of taxi dispatching strategies (1976)	paper in Transportation Research Record	illustrative applications only
Ed Pacholok, Streets and Transportation Division City of WInnipeg	1. Intersection capacity calculation for signalized intersections (1976) 2. Management of traffic operations system, developed by F.H.W.A. (U.S.), 1975	source listing only user's manual, sample input/output	practical applications in Winnipeg practical applications in Winnipeg
W.O'Brien Transportation Planning City of Edmonton	Transit Service Planning Model, determines transit service requirements and transit operating costs from route characteristics, ridership forecasts, and service policy contraints (1975)	user-oriented documentation report	practical applications in Edmonton

URBAN GOODS MOVEMENT MODELS

RESEARCHER & ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
T.O. Clement Transportation Planner City of Edmonton	Truck Movement Model - a set of simple models for forecasting the future interchange of trucks, by type, between various parts of the City (under development)	none presently available	practical applications planned in Edmonton
Harvey Kriss, Lee Sims IBI Group Toronto, Ontario	Urban Truck Traffic Forecasting Model, gravity model for forecasting trips within Metro Toronto and between Toronto and elsewhere	sufficient documentation for model use	practical applications in Toronto
Norman Allyn Swan Wooster, Vancouver, B.C.	Truck routes and terminal consolidation model, calculates the number of vehicles and associated cost required to efficiently carry a set of consignments throughout a city (1974)	documentation available from the Transportation Research Centre of Transport Canada	illustrative applications
N.D. Lea & Associates Oakville, Ontario	Urban Goods Movement System Models, Micro - a queueing model which simulates operations at a single endpoint Macro - a network flow model which calculates time and cost to transport goods over the system	model documentation in report produced for Transport Canada	illustrative and research applications

EVALUATION MODELS

RESEARCH AND ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
Harvey Kriss Peat, Marwick & Partners Toronto, Ontario	Municipal Financial Impact Model, simulates the financing of municipal services	Model described in Vol. 4 of Mississauga Urban and Transportation Study	practical application in Mississauga
T.O. Clement Transportation Planning City of Edmonton	Subjective Rating Program, allows any number of factors that are competing for a single limited resource (1976)	report describing model structure and use; sample run included	practical applications in Edmonton
M.A. Sargious University of Calgary J.J. Salinas, Carleton University Ottawa, Ontario	Alternative Project Evaluation Programs, evaluates alternative proposals first according to their economic viability and then reranks them according to their effectiveness in satisfying other objectives (1972-78)	user's manual and two papers on model application	illustrative applications
T.E. Kuhn S.F. Gribble York University, Toronto, Ontario	MIES - Micro/impact Evaluation System Use of macroeconomic input/output analysis for the evaluation of large scale transportation or other projects	user's manual and paper on model application	illustrative applications
Ministry of Transportation and Communications, Ontario	System No. 037 - Priority·Planning, records, evalutates, and prioritizes road construction projects on the basis of economic need and available budget	complete documentation available from Ministry of Transportation and Communications	practical applications in Ontario

OTHER MODELS

RESEARCH AND ORGANIZATION	DESCRIPTION	DOCUMENTATION AVAILABLE	APPLICATIONS
Ben Barkow Behavioural Team Toronto, Ontario	Pedestrian flow simulation model using computer animation (1974)	limited documentation available	illustrative applications
Dr. F. Navin Mr. P. Buckland Department of Civil Engineering University of British Columbia	Statistical vehicle loading on bridges, allows traffic engineering and land use variables to be studied in the design of long span bridges in urban areas	reports on model structure and use	applications in Vancouver
Ed Pacholok Streets and Transportation Division City of Winnipeg	Traffic accident analysis system, variety of programs including a before-after comparison program and a route analysis program	general descriptive documentation	practical applications in Winnipeg

APPENDIX B

DESCRIPTIONS OF THE SELECTED MODELS

DESCRIPTIONS OF THE SELECTED MODELS

TABLE OF CONTENTS

1. TITLE

DEMTEC: Demande de Transport en Commun

2. PRINCIPAL RESEARCHER

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3. AVAILABILITY OF MODEL

The estimation package required for the calibration of the DEMTEC model is useable without adaptation and can be obtained from the Centre de recherche sur les transports of the Universite de Montreal at no charge except for copying and administrative costs. There is documentation on the model structure and on an application of the model using data from Montreal (see Bibliography). A user's manual will be available by the beginning of 1979.

4. MODEL DESCRIPTION

4.1 Summary Description

The DEMTEC model is a demand equation which is used to explain the aggregate demand for public transit in terms of the prices of public and private transportation, the price level of non-transportation goods, service characteristics of competing modes, comfort levels, income and socio-economic variables, etc. The parameter values used in the equation are obtained through an estimation package, SEGAUCORC (Single Equation Generalized Auto Regressive Cochrane-Orcutt), which was developed by the principal researcher. The DEMTEC model was developed over the period 1972-75 using time-series data from the Montreal Urban Community Transit Commission (MUCTC).

The basic functions of the DEMTEC model are to explain past transit ridership levels, to forecast future ridership levels (and revenues) and to test the impact of specific policy changes (changes in fares or service levels) or of new accounting procedures.

The DEMTEC demand equation is obtained from the application of the SEGAUCORC estimation package to a set of selected time-series data. Specifically, equation parameter estimates are obtained by using a least-squares regression technique developed by Cochrane and Orcutt for relationships containing auto correlated error terms.

The estimation techniques can be applied to any set of time-series data. For example, the principal researcher has used the technique to estimate a demand equation for gasoline consumption.

The estimation package and its accompanying user's manual has been prepared in a manner such that a transit planner with some background in statistics or basic training in econometrics or regression analysis should be able to use the model. The specification of the variables to be used in the model must be performed by someone who is very familiar with the transit system and who could interpret the significance of the parameter values and ensure that the model is not misspecified.

The development of the model is complete, and it is regularly used by the MUCTC to explain past transit ridership and forecast future ridership. The model is also being implemented by the Toronto Transit Commission.

4.2 Inputs Required

Application of the DEMTEC model of aggregate demand for transit ridership requires time series data from the following classes: prices and income, service levels, comfort levels, activity levels and accounting or aggregation variables, as well as transit ridership. The specific variables which are used in the DEMTEC demand equation, and thus the historical data which would be required from each of the classes depends upon the transit system which is being modelled. As an example of the type of data which might be needed, some of the variables from the MUCTC adult market equation are presented below:

- Prices and income
  - MUCTC real fare
  - number of cars in the areas served by transit
  - consumer price index
  - real average earnings.
- Time variables
  - MUCTC wait time
  - MUCTC in-transit time
  - car in-transit time.
- Comfort variables
  - temperature discomfort: the absolute value of the difference between desired and actual temperatures
  - rainfall discomfort: the amount of rainfall
  - snowfall discomfort: the amount of new snowfall
  - cumulated snowfall discomfort: old plus new snowfall.
- Activity levels
  - job presence index
  - college-university presence index
  - shopping trip index
  - Expo '67
  - MUCTC strikes.
- Accounting and aggregation Variables
  - multiple fare zones, double counting
  - work days/month
  - Saturdays/month
  - Sundays and holidays/month.

Data on all of the independent variables and on the dependent variable, transit ridership, was obtained for each month over the period of time which was used for the initial calibration of the model. In Montreal the model is regularly recalibrated as more data observations become available.

When the model is used for forecasting transit ridership, values for all of the independent variables must be estimated. This input can be divided into two groups: environmental assumptions and policy variables. The first group includes those variables over which the model user has no control, such as the consumer price index, snowfall, and activity indexes in the Montreal example. Estimates of the values of these variables can come from the model user if they are not available from other sources. The second group of inputs, policy variables, are those over which the model user has some control, for example transit fares, MUCTC wait time and in-transit time in the Montreal case. The model user can assign different values to these variables in order to estimate the effects of different policy decisions.

The DEMTEC transit demand equation has a number of parameters whose values must be calibrated: one coefficient for each of the independent variables, a constant coefficient, and two serial coefficients which are used to account for the autocorrelation of the residuals.

4.3 Model Calibration

The parameters used in the DEMTEC model are calibrated by means of the SEGAUCORC estimation package which was developed by the principal researcher. The package utilizes a least squares regression technique initially developed by Cochrane and Orcutt for relationshps containing autocorrelated error terms. It can be shown that the technique converges to a maximum likelihood estimate of the parameters. The package also includes a technique based on Box-Jenkins for error analysis which helps to identify the structure that underlies the autocorrelation of the residuals.

The outputs of the calibration process include values for all of the model coefficients, the t-statistics associated with these values, other relevant statistics such as the R-squared value, the Durbin-Watson statistic and the standard-error of regression, and the demand elasticities or cross-elasticities of the independent variables. In most applications these outputs are of more interest than the forecasts which can be obtained from a calibrated demand equation.

4.4 Model Process

The process involved in applying DEMTEC as an aggregate transit ridership forecasting model is very straightforward. Estimates of the future values of the independent variables are combined with the calibrated parameters in a specified functional form to yield the dependent variable, transit ridership. This operation can either be done manually, or a short computer program can be written to perform the calculations.

4.5 Model Output

When used as a demand forecasting model, the output of DEMTEC is an estimate of the monthly transit ridership.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

The SEGAUCORC estimation package is written in Fortran and has been used on both IBM and CDC computers without any problems. There are no special requirements needed in terms of computer hardware. The average cost for a single calibration run which takes fifteen iterations and uses twenty years of data (240 observations) is twenty-five dollars. This assumes that the initial values of the equation coefficients are set equal to zero. If reasonable estimates of the coefficients are supplied, from a previous calibration run for example, far fewer iterations are required and the computer costs are lowered.

5.2 Time and Staff Requirments

A large proportion of the data required for the application of the DEMTEC model can be obtained from Statistics Canada. The model user should be able to obtain other necessary data, such as information on the transit system, with relatively modest effort. The data may have to be manipulated extensively so as to ensure that all of the values of any particular variable are measured in a consistent fashion over the time-series used for calibration.

Depending upon the availability and consistency of the data, roughly two to four man-months would be required for the initial data collection and calibration of the model. At the MUCTC the model is updated and recalibrated semi-annually. This process, which involves updating the time-series data set, adding new explanatory variables as required, recalibrating the demand equation and forecasting aggregate transit ridership in the near future, takes roughly three man-weeks.

The principal researcher feels that the model calibration should be done 'in-house' since the user must have a high degree of familiarity with the system which is being studied in order to ensure that the independent variables in the demand equation are correctly specified.

An evaluation of the calibration results requires a greater effort than an evaluation of the ridership forecasts. The user must examine the signs and magnitudes of the variable coefficients, and interpret the values of the various statistics and demand elasticities and cross-elasticities. The evaluation of a single calibration run should take roughly one hour once the user has some familiarity with the model.

6. APPLICATIONS

The MUCTC has been using the DEMTEC model regularly since 1975, while the Toronto Transit Commission is in the process of implementing the model.

7. BIBLIOGRAPHY

Gaudry, M., "An Aggregate Time-Series Analysis on Urban Transit Demand: the Montreal Case", Publication #6, Centre de recherche sur les transports, Universite de Montreal, 1975 and Transportation Research, Vol. 9, pp. 249-58, 1975.

Gaudry, M, "Seemingly Unrelated Static and Dynamic Urban Travel Demands", Publication #61, Centre de recherche sur les transports, Universite de Montreal, 1977 and Transportation Research , Vol. 12, pp. 195-211, 1978.

Gaudry, M., "A Study of Aggregate Bi-Modal Urban Travel Supply, Demand and Network Behavior Using Simultaneous Equations with Autoregressive Residuals", Publication #88 Centre de recherche sur les transports, Universite de Montreal, 1977. Forthcoming in Transportation Research B, 1979.

1. TITLE

TRANSIT DEMAND MODEL

2. PRINCIPAL RESEARCHER

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3. AVAILABILITY OF MODEL

The 'Transit Demand model' can be obtained from the principal researcher at no charge except for copying costs. A user's manual for the model is presently being prepared and should be available early in 1979. The model structure is documented in the papers referenced in the bibliography. The development of the model structure is complete and it can be applied by the user without modification.

4. MODEL DESCRIPTION

4.1 Summary Description

The 'Transit Demand Model' is a trip rate and elasticity type model which is oriented to short range operations planning and operates on a route by route basis. The model has been under development since 1974 and was designed to respond to the perceived need for a model of transit demand which can be applied easily at the route level.

The basic function of the model is to estimate the number of passengers boarding and alighting over different sections of a transit route from service parameters and socio-demographic data from the immediate vicinity of the route. To date, only routes oriented to the CBD (Central Business District) or terminating at a subway stop have been considered. Additional parameters are being added to the model so that cross-town routes can also be considered.

The model estimates transit ridership through sixteen separate direct demand equations. Each equation is associated with one of four time periods, either the inbound or outbound direction, and either boarding or alighting passengers. By means of this breakdown it is possible to relate bus ridership to land use data. For instance, in the A.M. peak period people will be travelling from homes(inbound boarding) to employment (inbound alighting) The values of the parameters used in the demand equations have been estimated by a calibration program used by the principal researcher. These parameters

are associated with the two classes of land use variables used by the model, households and attractions.

In addition to these parameters, a number of adjustment factors must be specified to account for such characteristics as transit fare, route headway and city size. The structure of the demand equations is discussed in the section 'Model Process.'

The model is relatively easy to use and could be applied by most transit planners and engineers. The development of the model structure is complete, and a set of parameter values is available. These values will be updated periodically as more data becomes available.

4.1 Inputs Required

For the application of the 'Transit Demand Model' a route is broken down into sections, usually 5-10 sections per route. These sections must be homogeneous with respect to headways of all bus routes serving the corridor. Since it is assumed that a bus rider will not board and alight the bus in the same section, it is necessary that the sections be a) not overly long and b) approximately the same length.

The following data are required by transit route section as input for the model:

- Number of Households
  - within 150 metres of the bus route and without a car
  - within 150 metres of the bus route and with a car
  - between 150 and 300 metres of the bus route and without a car
  - between 150 and 300 metres of the bus route and with a car

- Attraction Variables
  - total employment within 450 metres of the route
  - retail employment within 450 metres of the route
  - senior public and high school enrollment within 450 metres
  - university enrollment within 450 metres

The model can be used to estimate the effect of a number of policy changes. These include changes in fare or headway which are modelled by modifications to the appropriate adjustment factors, and changes in the route location which are modelled by altering the input data as required.

There are two types of parameters used by the model, those which have been specified by the principal researcher and those which the model user must specify. The former include the parameters associated with each of the household and attraction input variables listed above for the sixteen different parameter equations. The latter type consist of a number of adjustment factors which account for differences in fares, city size, route

headway and other characteristics. The parameters specified by the principal researcher are periodically revised as more data becomes available.

4.3 Model Calibration

The 'Transit Demand Model' was developed as a transferable model and the required parameters have been calibrated by the principal researcher. The model user can calibrate a city size adjustment factor which ensures that the overall predicted level of transit ridership matches the actual value. A trial and error process can be used to determine an appropriate value for the factor.

4.4 Model Process

The model uses sixteen demand equations to estimate the boardings (ONs) and alightings (OFFs) by route section for each time period and each direction (INBOUND and OUTBOUND). The basic equation structure is shown in Figure 1. Reference to Table 1 will help in the interpretation of this Figure.

TABLE 1

	ASSUMED RELATIONSHIP BETWEEN LAND USE AND TIME PERIOD AND BUS OPERATING CASE			
	1 Inbound Bus Pass. ON	2 Inbound Bus Pass.OFF	3 Outbound Bus Pass.ON	4 Outbound Bus Pass.OFF
Time Period 1 (a.m. peak)	Households → Attractions (journey to work)		Households → Attractions (journey to work)	
Time Period 2 (daily off peak)	Households → Attractions (work, shop, other)		Attractions → Households (return home)	
Time Period 3 (p.m. peak)	Attractions → Households (return home)		Attractions → Households (return home)	
Time Period 4 (evening off peak)	Household → Attractions (to shop, entertainment)		Attractions → Households (return to home)	

In addition to the demand equations the model process includes a balancing procedure which ensures that the total number of boardings during the day equals the total number of alightings.

FIGURE 1: DEMAND EQUATION STRUCTURE

$$\begin{matrix} ONs_j \\ \text{or } OFFs_j \end{matrix} = \left(\sum_i a_{ik} \; L_{U_{ikj}}\right) \left(\sum_s \sum_i \left(a_{ikk} \; L_{U_{ikks}}\right)\right) \begin{matrix} (HF_j)(AF) \\ \text{or} \\ HF_s \end{matrix}$$

where ONs_j or $OFFs_j$ - is the number of boarding or exiting passengers in a section j in a time period (not indexed)

k - land use set -either Household or Attractions
if k = Households then kk = Attractions
if k = Attractions then kk = Households

i - land use variable i in set k or kk

$L_{U_{ijk}}$ - land use in set k of type i in section j

a_{ik}, a_{ikk} - model coefficients for set k land use type i

s - all other sections up route or down route from j
e.g. consider ONs Inbound (a.m. peak) with j = 5
then s = 1,4 . Also k = Households and
kk = Attractions

HF_j - the Headway Factor for section j <u>if</u> k = Households

HF_s - the Headway Factor for all section s <u>if</u>
k = Attractions.

Note that the headway factor is always attached to the household land use set.

AF - other adjustment factors such as for fares, bus condition, etc

4.5 Model Output

The main outputs of the 'Transit Demand Model' are predictions of the number of transit users boarding and alighting in each section of the route during the four different time periods and in the two directions. In addition, if the revenue per passenger and the number of equivalent week-days per year are supplied by the model user, the daily and annual number of passengers and passenger revenue will be calculated.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

The model computer program is written in Fortran and can be run on most installations. There are no special requirements for data storage or for specialized hardware. The time and cost requirements for a typical run are minimal.

5.2 Time and staff Requirements

The input data required by the model can be obtained with a relatively modest effort. Information on the number of households along the transit route can be obtained from aerial photograps while employment levels could be estimated from the photographs in combination with Statistics Canada data or they could be obtained through a local survey. The preparation of data for a transit route could take from two to five man-days depending upon the availability of the data.

The requirements for the calibration of the model are minimal - one complete run in order to determine an overall adjustment factor. The time and staff requirements needed to test changes in policy variables depend upon the type and extent of the changes. Generally one or two man-days would be sufficient. Since the output is in relatively direct form, the evaluation of the results is straightforward.

6. APPLICATIONS

The 'Transit Demand Model' has been applied to the transit systems in Kitchener - Waterloo and in Cambridge, Ontario. In addition the model has been applied to six transit routes in Ottawa, and further investigation of the performance of the model is underway using data from eleven routes in Edmonton.

7. BIBLIOGRAPHY

Shortreed, J.H. and Maynes, D., "Calibration of Transit Demand for Kitchener-Waterloo", Project Report WRI 606-11, Ministry of Transportation and Communications Ontario, Toronto, 1977.

Shortreed, J.H. "Transit Demand Models", Public Transport Systems in Urban Areas - Volume C", Proceedings of the International Conference and Exhibition in Göteborg, Sweden, June 1978.

1. TITLE

A Transportation Planning Model
for Detailed Traffic Analyses

2. PRINCIPAL RESEARCHERS

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TEL: 605-224-7867

3. AVAILABILITY

Presently some modifications and improvements are being made, however, the program is completed and operational, and will not require any adaptations. The Fortran program is available at cost to anyone by contacting the Civil Engineering Department at U.B.C., and documentation is available along with a user's manual which is soon to be completed (early 1979).

4. MODEL DESCRIPTION

4.1 Summary Description

This model, developed over four or five years, is essentially a stochastic traffic assignment procedure to be used in smaller areas, such as the CBD, where the movement of automobiles, transit and pedestrians is modelled taking into account the interaction between and within each of the traffic components including parking. The network descriptions required are very detailed - block-face data - including number of road lanes, traffic controls, signal timing, turning restrictions, etc.

The principal objective of the model is to generate vehicular and pedestrian link volumes in graphical form as well as printed travel statistics including detailed intersection delay analyses for traffic engineers. The output can be used to evaluate the effect of any number of network modifications, parking policies, land use alterations, transit service improvements or growth overtime. In order to examine the implications of policy or environmental assumptions, their effects must be translated into acceptable input values such as increased traffic movements for particular origins and destinations, or decreased parking facilities.

The model is a set of programs that "cascade" toward the final assignment of traffic and descriptive statistics. The major steps in the procedure are: first, computer representations of the streets, sidewalks and transit routes. Second, given traffic at entry points into the study area and final

destinations, the vehicle portions of the trips are "optimally" assigned to parking lots. Third, the pedestrians from transit and vehicles are assigned to sidewalks and the demand for street crossing is generated. Finally, the vehicle assignment to the streets is made taking into account the interaction of the various traffic streams. To date the model has been designed to determine traffic movements on a downtown or CBD network for the morning peak peiod only.

The model procedure would be understandable to most traffic engineers and planners with the possible exception of the interface with the plotter and display units. However, in-house computer staff is available, should be able to overcome any problems in this area.

4.2 Inputs Required

There are five basic data files that serve as input to the model:

File 1: coordinates of study area (for plotting)

File 2: road intersection data which include:
- location coordinates
- unique identification number
- controlled intersection identification (yes or no)
- signal cycle time in each direction
- pedestrian green time in all directions
- turning delay times

File 3: block face data which include:
- location using O-D intersection numbers
- name identification
- maximum speed
- number of lanes
- pedestrians yes or no
- block-face number indicating direction
- turning movements at destination intersection
- bus stops and transit service
- travel time
- pedestrian walking time along block-face
- parking spaces and charges

File 4: origin-destination movements:
- vehicles
- pedestrians

File 5: program parameters and options which include the following general categories:
- network characteristics
- plotter parameters and options
- printer options
- program options
- vehicle statistics
- transit statistics
- pedestrian statistics
- model parameters
- socio-economic data, e.g., costs of time for various classes of people

The data requirements are considerable, with the origin-destination data being the most significant data collection step. All inputs can be caried and will generally be unique to each study area. The program is very flexible and can be run on subsets of the total data, such as just for the trasit mode, to the exclusion of the others.

Several parameters utilized in the model must be supplied by the user based on tests in the particular locale of the study area; these are:

<u>Vehicle statistics</u>:

Acceleration (m/s**2)
Deceleration (m/s**2)
Time at stop sign
Turning velocity (Km/h)
Gap acceptance interval (s.)
Vehicle length + gap (m)
Reaction time for first vehicle
Reaction time for following vehicle
Vehicle headway (s.)

<u>Transit statistics</u>:

Acceleration (m/s**2)
Deceleration (m/s**2)
Time at stop sign
Turning velocity (km/k)
Delay at bus stops (s.)

<u>Pedestrian statistics</u>:

Walking speed (Km/h)
Walking time cut off
Crossing time (s.)
Min. walking distance
Max. walking distance

<u>Model parameters</u>:

Calibration parameter
Assignment period (min)
No. of cars/bus
Average travel time
No. of groups
Fraction of volume
Fraction of period

<u>Socio-economic groups</u>:

<u>Cost ($/min)</u>
Walking
Travel

4.3 Model Process and Calibration

The model consists of a set of modular programs (see Exhibit 1) designed to work interactively or independently with a single traffic system analyzed to the exclusion of the others. The network is defined by a set of block face data describing traffic movements along each block front, together with a set of source and sink nodes that introduce and absorb traffic from the system. The first stage involves a series of network building programs for pedestrian, vehicular and transit traffic based on the block face data. (These programs also search for logical errors in the network.) The format of block face input reduces the coding effort and greatly facilitates the generation of graphical output.

Vehicular traffic in the AM peak is represented by an O-D matrix. Vehicles are removed from the network either at parking locations or external sink nodes. If only work location is known, a parking allocation algorithm, based on a user optimization hypothesis, may be used to generate the O-D information. The transit component is derived from O-D survey data and the pedestrian component is developed from bus stops and parking locations relative to work locations.

Vehicle and pedestrian assignments are effected using the Dial multipath assignment algorithm (Dial, 1972) which is employed incrementally: link travel times are revised after each increment taking into account the various traffic stream interactions. Delay functions are derived for such interactions and are introduced to network travel times.

Final link volumes are produced in plot form together with a detailed description of traffic movements at each intersection. Travel statistics including vehicle hours and miles travelled, vehicle delay, average speed and number of vehicle conflicts are calculated.

Within this process there are three major components which are of prime interest to the user:

1. parking allocation model,
2. assignment model, and
3. link travel times.

Each of these will be briefly outlined in the following paragraphs which emphasize user decision points and/or inputs, including the principal calibration variable, viz., θ (theta) in the assignment model.

Parking Allocation Model

If the vehicle O-D data denote only cordon entry point and place of work, then it is necessary to determine vehicle parking locations. To do so a linear programming model was developed that optimally assigned vehicles to available parking lots taking into account the walking time from the

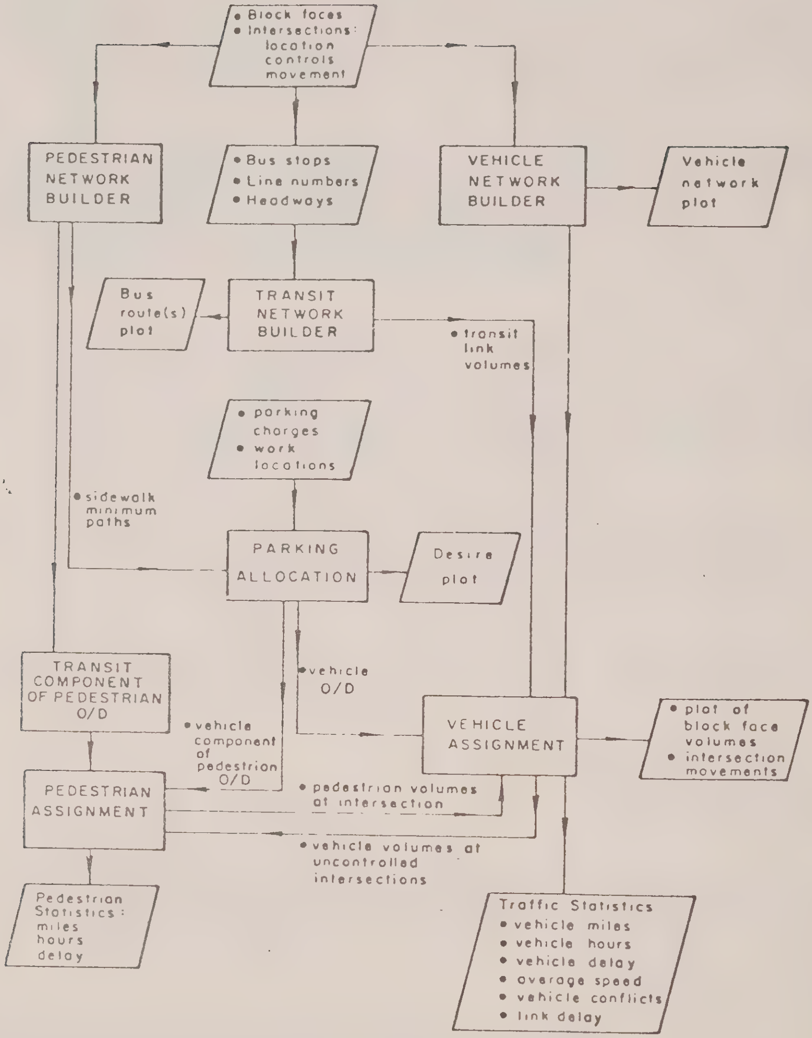


Exhibit 1. Modular structure of model components.

car park to the work location and parking charges. Once a vehicle is parked pedestrian traffic to place of work can be generated if the vehicle occupancy ratio is known. The objective function for parking allocation is given by:

$$\sum_{g,j,k} {}_{jk} \mid {}^{w}{}_{jk}{}^{g} + c_{j} \mid$$

where $\theta_{jk}{}^{g}$ = 'cost' of walking from j to k for group g (using the indifference circle method - Ergun, 1971)

cj = parking cost at location j

The constraints imposed on the solution are:

$$\sum_{j} \theta_{jk} = \theta_{k}^{g} = \text{no. of trips in group g whose destination is k.}$$

$$\sum_{g,k} \theta_{jk}{}^{g} \leq S_{j} = \text{where } S_{j} = \text{parking capacity at sink j}$$

Assignment Model

In the Dial multipath assingment, the number of trips allocated to path p between source i and sink j is proportional to

$\exp \ \theta t_{ij}{}^{p}$ where $t_{ij}{}^{p}$ = travel time along an 'efficient' path p between i and j

θ = a model parameter that determines the dispersion of trips along paths of different lengths for a given source and sink

In the vehicle assignment model θ is calibrated using the maximum likelihood technique (Fisk, 1977). For the pedestrian assignment, 0 is assumed to be large as only the shortest paths will carry the major portion of the traffic.

Link Travel Times

Link travel times are developed as a function of : (1) traffic volumes, (2) physical characteristics of the link, and (3) interaction between traffic streams (Brown et al, 1970). The latter involves the derivation of pedestrian and vehicle delay functions which are assumed to occur at intersections only. The vehicle delay function has two components:

1. a zero volume delay due to vehicle acceleration and deceleration, and
2. volume delay caused by interaction with other streams of traffic.

In the case of interacting traffic, separate functions are derived for controlled and uncontrolled intersections with turn penalties along with pedestrian and transit interaction. These functions have satisfactorily replicated traffic movements in the Vancouver area and may be applicable in other CBDs.

4.4 Model Output

Once all the traffic is assigned, a set of summary statistics are printed out. These include global pedestrian and traffic characteristics – miles travelled, delay times, etc. – all of which can be used in an overall comparison of different network configurations. Vehicle, transit and pedestrian volumes are printed out in tabular form for all block faces and intersection volumes are also available. The graphical output is either for the entire network or for individual intersections: examples of graphic displays that can be generated are provided in the accompanying Exhibits.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

This model was developed on a IBM/370 computer using the Michigan Terminal System (MTC) and the programs are written in FORTRAN. The model requires interface with a CRT with copier attachment as well as a Calcomp plotter (usually interfaced with PDP 11). Although the storage requirements for reasonably sized problems, e.g. Vancouver CBD, are not excessive, around 150K, only a large computer facility will usually have the necessary peripheral equipment to fully utilize the model. The time required to run the program for the Vancouver CBD with some 300 intersections is about 30 seconds which is relatively cheap and the large plots cost up to $30,00 each (total study area).

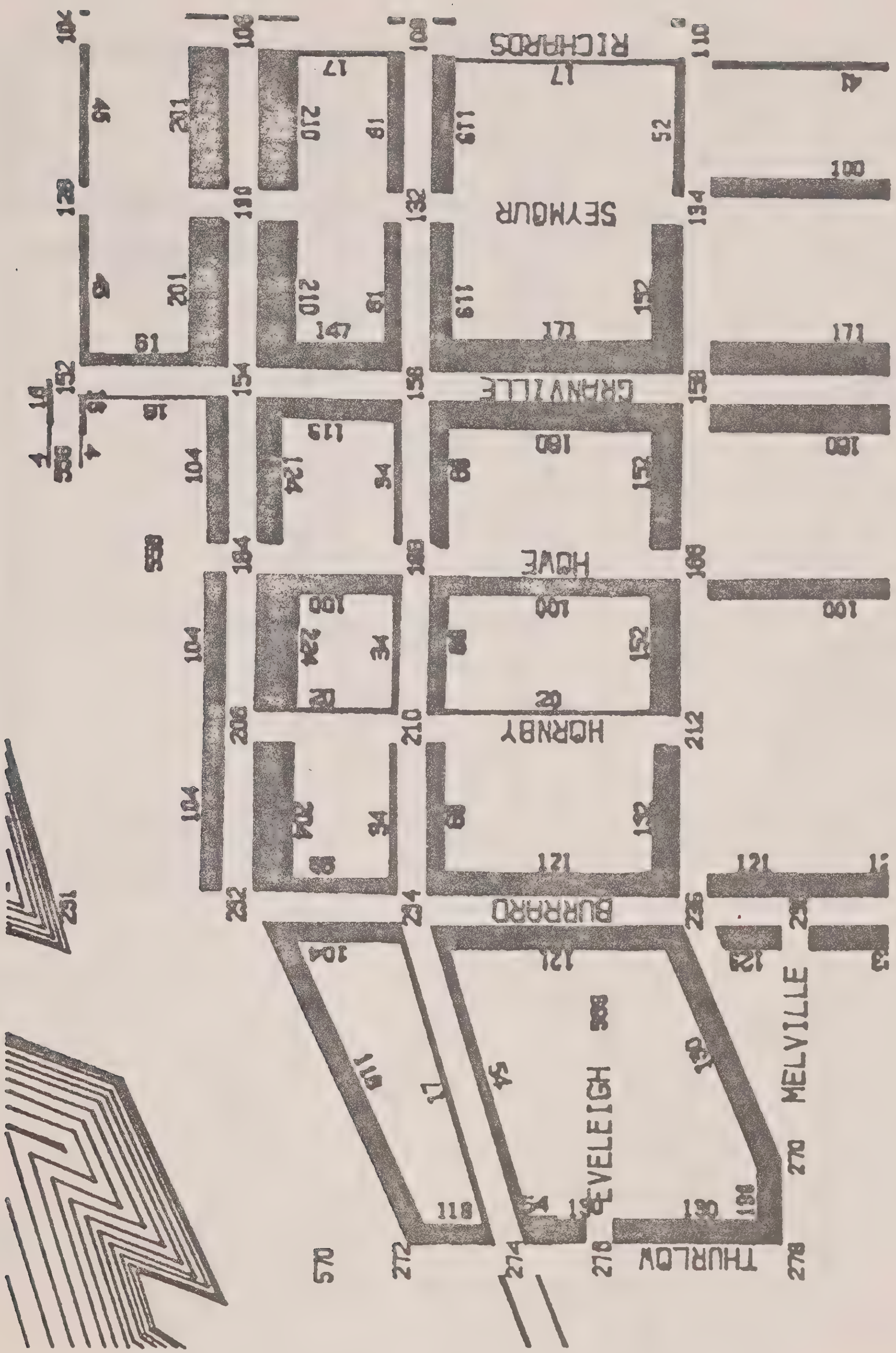
5.2 Time and Staff Requirements

The input data for the model, particularly the O-D data and block face coding, is relatively time consuming and labour intensive to collect. However, the real payoff to planning agencies is that there is an estimated fifty per cent reduction in response time to evaluate major developments or street alternations. Furthermore, smaller developments can be examined on a system-wide basis to ensure full comprehension of the total impact.

The development of accurate model parameters also appears to be a time consuming task while calibration is a relatively straightforward excerise. Becaue the results can be graphically displayed and specific changes noted, the staff should have little trouble interpreting the results.

6. APPLICATIONS

The model has been applied to practical problems in both Vancouver and Richmond, British Columbia.

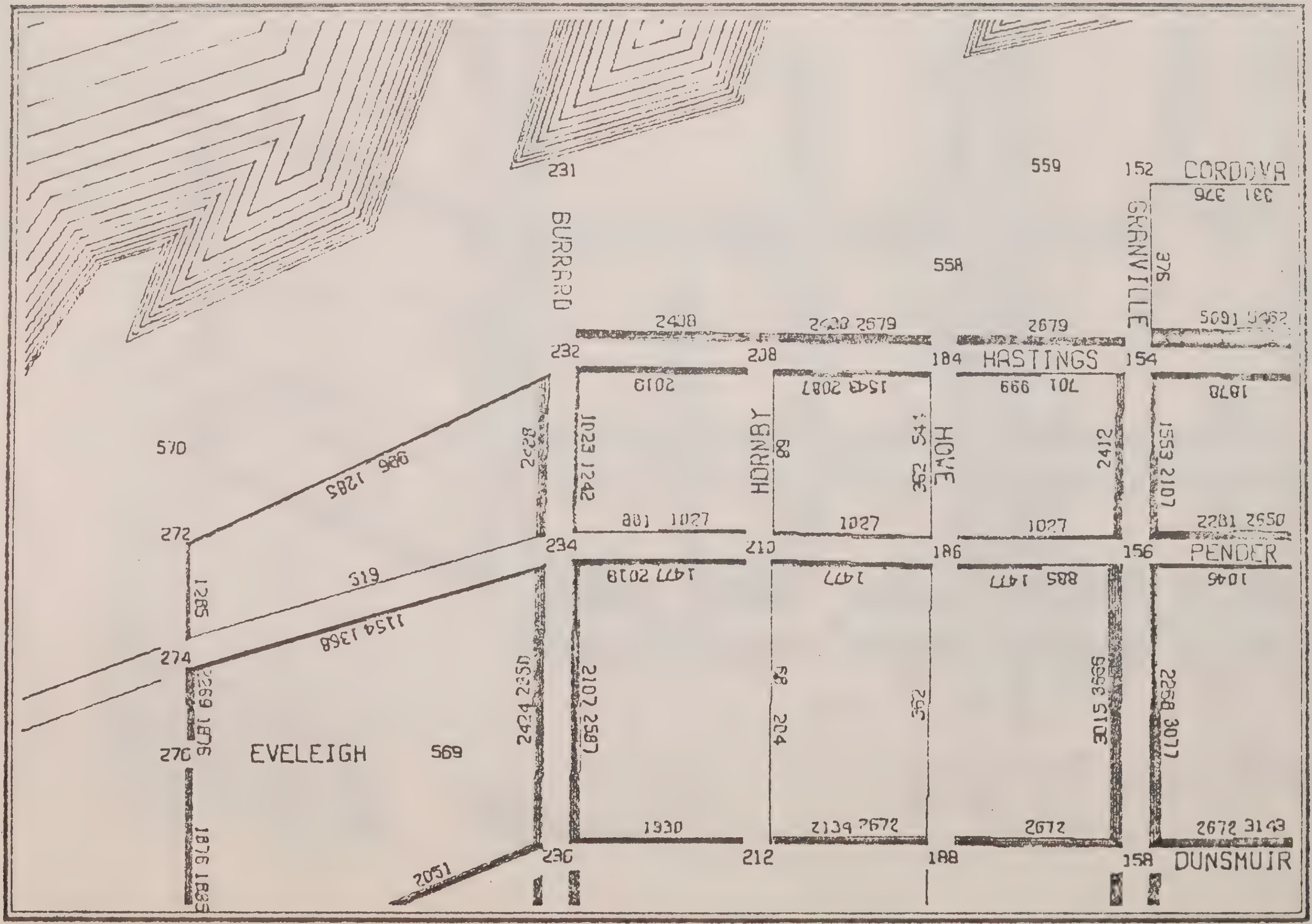

RICHARDS
SEYMOUR
GRANVILLE
HOWE
HORNBY
BURRARD
MELVILLE
EVELEIGH
THURLOW

IG

DOWNTOWN VANCOUVER

PASSENGER VOLUMES

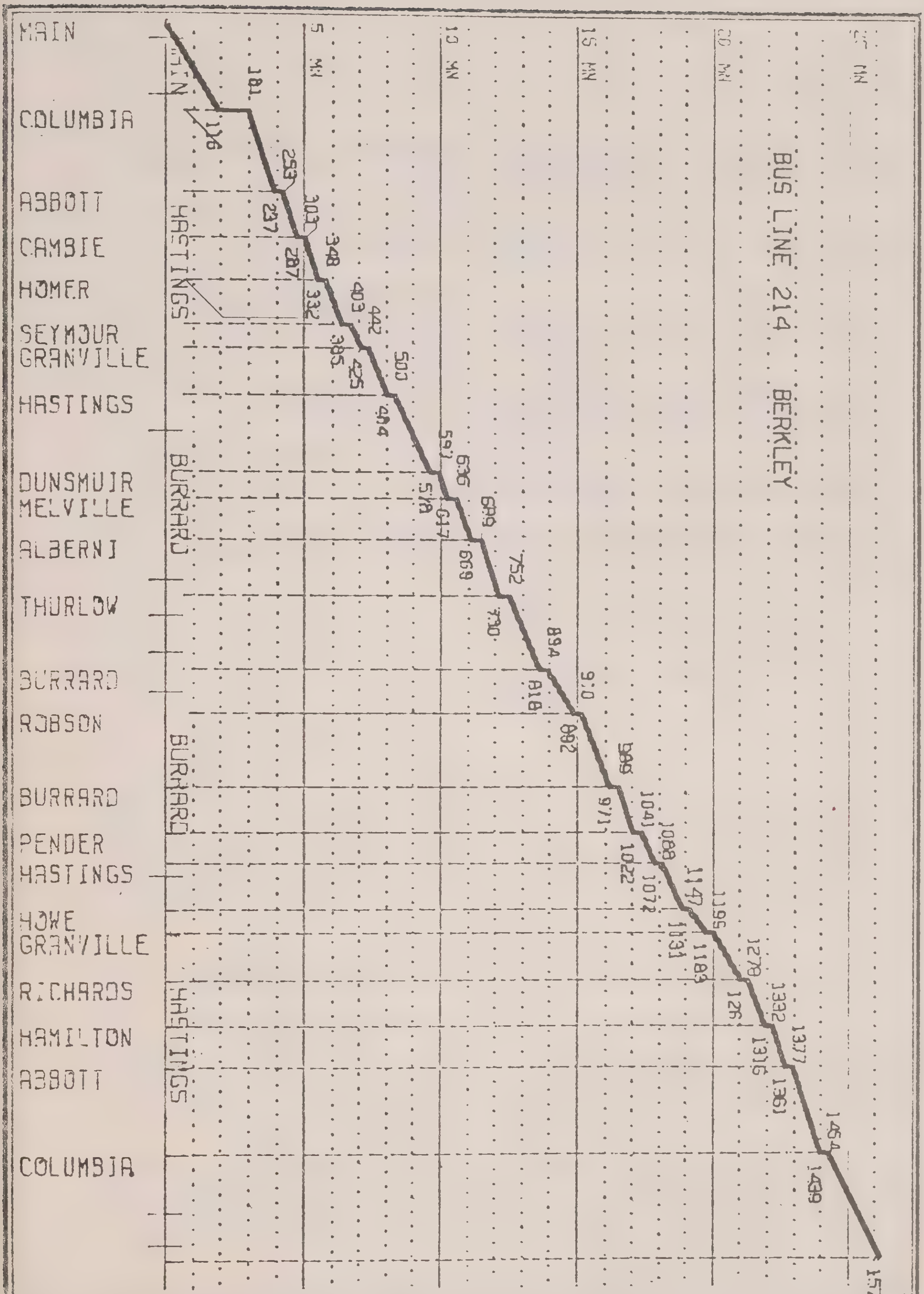
SCALE 1" = 79 M.



DOWNTOWN VANCOUVER

TRAVEL TIME

SCALE 1" = 640 M.



7 BIBLIOGRAPHY

Brown, G.J.H., and R.S. Scott, 1970, Micro-Assignment: A New Tool for Small-area Planning, Highway Research Record, No. 322, pp. 149-161.

Dial, R.B., 1972, A Probabilistic Multipath Traffic Assignment Model Which Obviates Path Enumeration, Transportation Research, Vol. 5, pp. 83-111.

Ergun, G., 1971, Development of a Downtown Parking Model, Highway Research Board, 50th Annual Meeting, Washington, D.C.

Fisk, C., 1977, Note on the Maximum Likelihood Calibration of Dial's Assignment Method, Transportation Research, Vol. 11, pp. 67-68.

Fisk, C., 1978, A Transportation Planning Model for Detailed Traffic Analyses, Canadian Journal of Civil Engineering, Vol. 5, pp. 18-25.

Velerda, R., 1978, Urban Transportation Model, User's Manual, Department of Civil Engineering, University of British Columbia.

1. TITLES

CORQ - Corridor Traffic Modelling Technique

CORCON - A Freeway Corridor Assignment and Control Model

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3. AVAILABILITY OF MODELS

Both models can be obtained from their respective principal researchers. They can be used to model most freeway corridors without modification to the computer programs if the appropriate data is supplied. Sufficient documentation is available so that a user can probably apply the models without outside help.

4. MODEL DESCRIPTIONS

4.1 Summary Descriptions

CORQ is a corridor traffic modelling technique which assigns time-varying origin-destination demands to freeway and major adjacent arterials. CORQ was developed by Yagar over the period 1970 to 1973.

CORCON, also a freeway corridor assignment model, was developed by Easa and Allen during 1974-76. The model's basic assumptions and framework were taken from Yagar's CORQ model. The differences between the two models are described in the appropriate sections of the following documentation.

The basic function of both models is to predict traffic behaviour in a freeway corridor by assigning time-varying origin-destination demand to the freeway mainline and surrounding network streets. They are intended to enable a

traffic analyst to assess the system-wide effects of any proposed changes to the corridor network, such as ramp metering or control.

The basic technique used by the two models divides the peak period into a set of time slices of common length, sufficiently short that the rates of demand between each O-D pair can be considered constant over the interval- of the order of 15 minutes, say. This allows the time-varying demand to be expressed as a set of O-D matrices representing the respective time slices, with each slice having stationary demands. The O-D matrices are assigned to the network sequentially in time. The method allows temporary over-saturation of network links. That is, in any time slice certain network links may have more demand assigned to them than they can serve. The excess vehicles queue on upstream links and are re-assigned to their destinations in the succeeding time slices from the points at which they queued.

In the CORQ model, traffic assignment is based on the principle of individual travel cost (time), where the minimum cost path may include some time in queue. The cost of queuing is dynamically approximated as directly proportional to the size of the queue and inversely proportional to the rate at which the queued vehicles are served.

The CORCON model first assigns the demand to the minimum paths in the corridor network according to Wardrop's first principle, where each user minimizes his own individual travel (cost) time. When a minimum path contains one or more queuing links, the algorithm searches for the least cost alternative non-queuing path available. If such a path exists, it is assumed that a portion of the demand will divert to the non-queuing path according to a specified diversion expression.

In both models the flow versus travel time relationship for each link is an increasing function and is approximated by three linear components.

Both models are reasonably easy to understand and apply and could be used by most transportation planning departments, who have jurisdiction over freeway corridors, without any requirements for outside help. Neither model is presently under active development, although both Yager and Allen have suggested areas for further research and development.

4.2 Inputs Required

The data required for the calibration and application of the CORQ model includes:

i) Network characteristics - the following information is required for each link in the network: a link identification number, the upstream and downstream nodes of the link, the flow versus travel time relationship and the capacity of the link, the number of vehicles on a link which will cause queue spillback and the upstream effects of the spillback, data on merge sections.

ii) Demand patterns - origin-destination trip matrices are required for each time slice. Initial estimates of the O-D patterns are altered in a trial and error fashion so that the model reproduces the observed flows and queues.

iii) Link volumes and queues - this information is required for each time slice for model calibration.

The data requirements of the CORCON model differ slightly in the link-node representation of the corridor. CORCON incorporates a new method of network representation which allows more than one link in the same direction to have common upstream and downstream nodes. This facility simplifies the representation of network components such as interchanges, intersections, and merging and weaving sections. However, this representation requires extensive use of turning prohibitions which make the shortest path procedure more involved.

The policy variables which can be used in applications of the CORQ and CORCON models include most of the network characteristics, and the origin-destination demand in some instances. Specifically, freeway ramps could be closed or metered, intersections could be improved, or demand patterns could be altered through the implementation of staggered hours or other similar procedures.

The CORQ model requires that the following five parameters be defined:

- length of a time slice in hours

- the fraction of possible shared merge capacity which is committed in the present increment

- amount by which unit cost in previous slice is weighed into present slice

- amount by which unit cost in previous iteration is weighed into present iteration

- fraction by which original O-D matrices are increased to give required demand level.

The principal researcher provides suggested values for some of these parameters and the user must define the others.

The CORCON model requires the first two parameters listed above as well as a diversion parameter, r, which is used in the traffic assignment component of the model. Its value is determined during model calibration.

4.3 Model Calibration

Both models use trial-and-error methods to calibrate the origin-destination trip matrices and the values of some of the parameters. When the CORCON

model was applied to a freeway corridor in the City of Mississauga the calibration process included the preparation of a combined trip table for both freeway users and non-users, and the determination of the best diversion parameter value.

To fabricate the freeway non-users O-D demand a trial-and-error procedure was adopted. First, a preliminary O-D demand of freeway non-suers was established. The minimum paths that the freeway users would choose were hypothesized and the freeway non-users on each link were calculated from observed link volumes (observed link volume minus the freeway user volume). Although freeway non-users have different origins and destinations, the principal researches felt that their route selection process was not likely to be particularily sensitive to varying control strategies. Knowledge of the actual origins and destinations was therefore not considered essential and the non-user O-D's were appropriately selected such that resultant link volumes matched with observed values. Subsequently, demand volumes were established for a preliminary corridor O-D trip table.

To establish the value of the diversion parameter it was assumed that diversion of freeway users from controlled ramps depends principally upon alternative travel cost characteristics in the corridor. In CORCON, those characteristics are approximated by linear components which provide a range of flow within which the link cost remains constant. The exact non-user link volume is therefore not necessary and the preliminary non-user O-D demand could be viably used in establishing the diversion parameter value. Consequently, to estimate the value of the diversion parameter for the entire corridor, a representative link was selected on an alternative route for diverted traffic. The model was used to predict traffic volumes on that link for different values of the diversion parameter. These volumes were compared with observed volumes and the best value of the diversion parameter was selected as that value which minimized the discrepancy between the calibrated and actual volumes.

The parameters of the CORQ model are estimated on the basis of the complete network, although, as in the CORCON calibration, the desire is to produce flows and queues which are reasonably close to the observed values.

4.4 Model Process

The logical sequences of the CORQ and CORCON models are shown in Exhibits 1 and 2 respectively. Some of the assumptions and approximations which the models use have been described earlier; others which have been included in the modelling process of both CORQ and CORCON are:

1. A queue formed in a certain time slice is assumed to be fed back to the network in the next time slice along with its original demand pattern

2. A queue which dissipates in a certain time slice is assumed to decrease at a constant rate during the whole length of that time slice.

3. Each type of movement at an intersection is assumed to have a constant through-flow equivalent independent of the number of vehicles making that movement.

4. A driver using the corridor in a certain time slice is assumed to know the flow and queuing costs for all links in that and subsequent time slices.

4.5 Model Output

In the CORQ model, output is given after each increment, interation and time slice. After each assigned increment the cumulative assigned fraction of the O-D matrix is printed along with its complement, the remaining fraction. The number of the "critical" link for that increment is printed along with that link's attempted assignment and its allowed assignment in that increment. The "critical" link is that link with the greatest ratio of attempted assignment to allowable assignment in that increment. The iteration ends when the above ratio does not exceed 1.0 for the critical link. At this point the cumulative assignment reaches 1.0

After each iteration the flow in that iteration on each approach of each merge section is printed, along with the leftover queue at the end of the iteration for the approach. The merges are labelled "freeway" and "on-ramp" in line with the common occurrence of capacity-sharing merges.

The flow and unit travel cost in the final iteration of the time slice is printed for each link. The links are identified by their upstream and downstream nodes. The information is printed in order of upstream node number, with a separate line for each group of links having a common upstream node. After each such group of links the cumulative total cost is printed (in seconds).

In the CORCON model, two types of information are output; initial output and time slice-related output. The initial output includes a summary of the main input parameters and turn prohibitions which are automatically determined by the program. In addition, a complete description of the link characteristics (used as input to the model) and original data of freeway merging sections is given. For each time slice CORCON outputs four main parts:

1. Output of new link characteristics (e.g. weaving capacity) and merge characteristics (e.g. entrance ramp capacity or metering rate).

2. Increment-related output. This part is optional and may be used to print after each increment in the assignment the cumulative assigned fraction of the O-D demand table and the critical link along with the allowable and attempted assignment.

3. Iteration-related output. Predicted volumes and queues on each freeway and entrance ramp merging section are given.

4. Final output. Link-flow characteristics including predicted volume and travel time are tabulated. Other tables identify links reaching capacity and those with queues (includes the

predicted queue length). Additionally, the total corridor travel time (vehicle hours) is printed. Finally, graphic output is printed for turning volume calculations at specific intersections.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

Both model programs are written in Fortran and can be run on most computer installations with no special hardware requirements. The costs for running the programs are similar and are highly dependent upon the size of the network which is being modelled. The QEW application of the CORCON model cost roughly 30 to 40 dollars for a run consisting of eight time slices. In this application there were approximately 55 nodes, 100 links and 50 O-D pairs with non-zero demand.

5.2 Time and Staff Requirements

The models use some normally accessible traffic engineering data such as link volumes and capacities. Other data, such as origin-destination trip matrices for each time slice, would probably have to be collected specifically for any application of the models. Data manipulation would involve adjusting the O-D trip tables so that the observed flows and queues are replicated. The effort required for this task could range from moderate to substantial. The manipulation of the data used in the QEW application of the CORCON model took approximately two man-weeks.

Both models could probably be used "in-house" by most transportation departments who would be involved in freeway modelling, although Yager feels that outside help would be very useful. The time and staff requirements for putting the model into a position where policy changes can be modelled depends a great deal on the quality of the data available and the success of the manipulation process. Once the models are calibrated the time required to model various alternative strategies and intrepret the output is roughly one day.

6. APPLICATIONS

The CORQ model had a practical application on the Queensway corridor of Ottawa in 1972 and a research application on the San Francisco Bay Area Eastshore corridor in 1973. The CORCON model was applied to a section of the Queen Elizabeth Way (QEW) corridor in the City of Mississauga in 1975.

7. BIBLIOGRAPHY

CORQ 1. S. Yagar, "Dynamic Assignment of Time-Varying Demands to Time-Dependent Networks", Transportation Development Agency, Ministry of Transport, Canada, 1974.

2. S. Yagar, "CORQ-A Model for Predicting Flows and Queues in a Road Corridor", TRR 533, pp. 77-86, 1975.

3. S. Yagar, "An Analysis of the Morning Peak Traffic Problems in the Eastbound Corridor Serving Ottawa", Ontario Ministry of Transportation and Communications, 1973.

4. S. Yagar, "Emulation of Dynamic Equilibrium in Traffic Networks", Proc. International Symposium on Traffic Equilibrium Methods, Montreal, November, 1974.

5. S. Yagar, "Applications of Traffic Flow Theory in Modelling Network Operations", TRR 567, pp. 65-69, 1976.

CORCON

1. Allen, Brian L. and Easa, Said M., Analysis of Urban Freeway Corridors: A Corridor Model for Assessing Freeway Control Plans. Final Report 3311-77/2: Volume 1, Department of Civil Engineering, McMaster University, Hamilton, Ontario, March, 1977.

2. Allen, Brian L and Easa, Said M., Analysis of Urban Freeway Corridors: Field Validation of CORCON - A Corridor Model for Assessing Freeway Control Plans. Final Report 3311/77/3: Volume 2, Department of Civil Engineering, McMaster University, Hamilton, Ontario, March, 1977.

3. Easa, Said M. and Allen, Brian L., CORCON: A Freeway CORridor Assignment and CONtrol Model, Department of Civil Engineering, McMaster University, Hamilton, Ontario, August, 1977. (Paper presented at 1978 annual meeting of TRB.)

4. Allen, Brian L., Easa, Said M., and Case, E.R., Application of a Freeway Corridor Assignment and Control Model, Department of Civil Engineering, McMaster University, Hamilton, Ontario, August, 1977. (Paper prepared for presentation at 1978 annual meeting of TRB.)

EXHIBIT 1

A BASIC OUTLINE OF THE LOGICAL SEQUENCES OF THE MODEL WHICH ARE PERFORMED BY THE COMPUTER PROGRAMME -- A SUMMARY OF THE PROGRAMME

Initialization Routine

Variable definitions and dimensions

Format statements

Data initialization

Read in the initial data: (i) job parameters
(ii) network description

Routine for Each Time Slice

1. Initialization of counters and variables
2. Read in any changes in network characteristics which take place in that time slice
3. Set O-D matrix equal to queues from previous time slice and add on the demand for the new time slice

Routine for Each Iteration of the Time Slice

I. Reset appropriate counters and variables

Routine for Each Incremental Assignment of the Iteration

A. Reset appropriate counters and variables
B. For each origin node (Oi) having some demand
    (a) Find tree of shortest paths to all destinations
    (b) For each Destination node (Dj)
        (i) Work back from that destination to the origin, noting the first point of congestion in the "origin to destination" path
        (ii) Tentatively assign the flows and queues that would result if all of the remaining demand from Oi to Dj were being assigned.
C. Find the critical sublink which limits the fraction of the tentatively assigned flows and queues that can be actually assigned in that increment.
D. Assign the appropriate fraction of the tentative assignment, as determined in C above.
E. Estimate the weaving section capacities on the basis of the assigned flows.

F. If it is desired to dynamically share the merge capacity, estimate the component capacities for each merge on the basis of the weaving capacity, respective merge entitlements and assigned merging flows.

G. Update the statistics for each link.

H. If the whole O-D matrix has not been assigned, perform the incremental assignment routine again.

II. Store the unit cost determined for each link during present iteration.

III. Print out merge flows and queues for present iteration.

IV. If it is desired to vary the entitlements from iteration to iteration, estimate merge capacity entitlement for the next iteration on the basis of demands and ultimate entitlements.

4. Print the results of the final iteration for the time slice.

Termination Routine after Final Time Slice

Print out any leftover queues as well as total travel time.

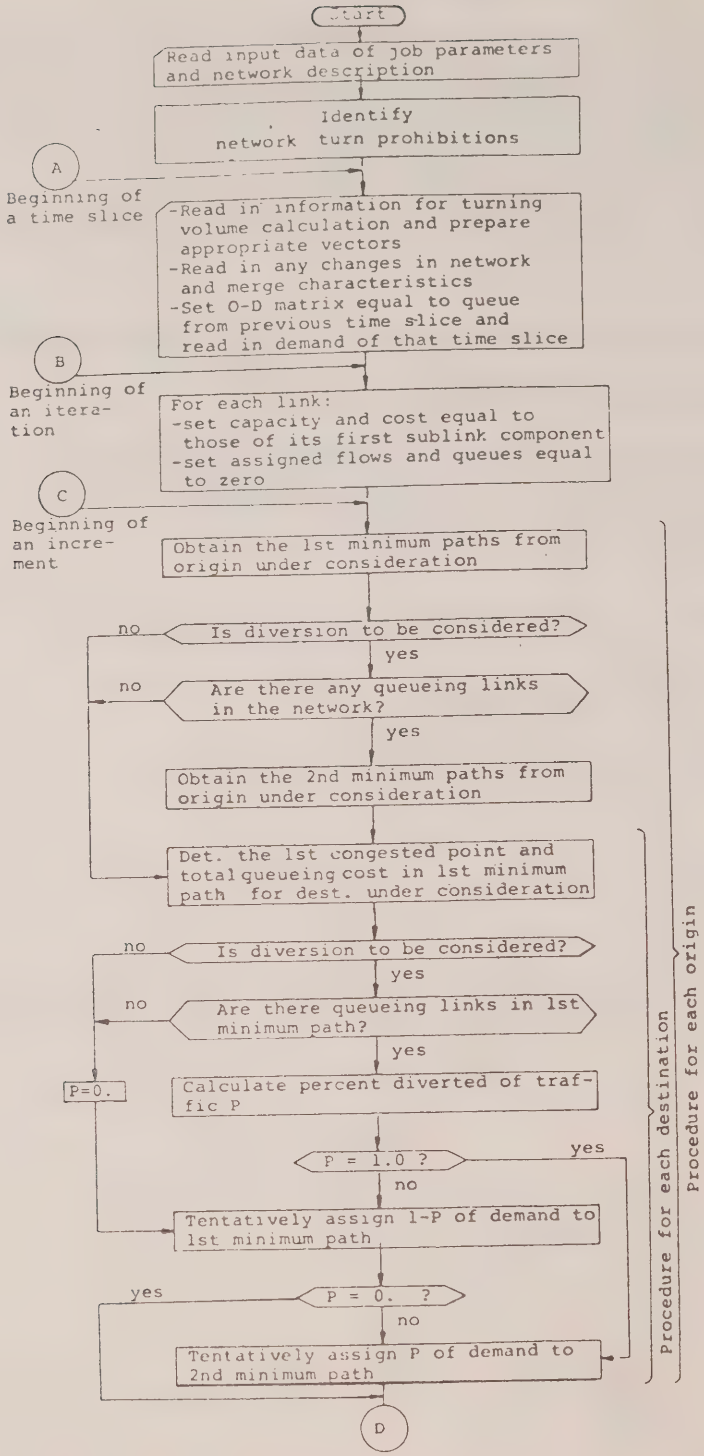

EXHIBIT 2 - LOGIC SEQUENCES OF THE MODEL

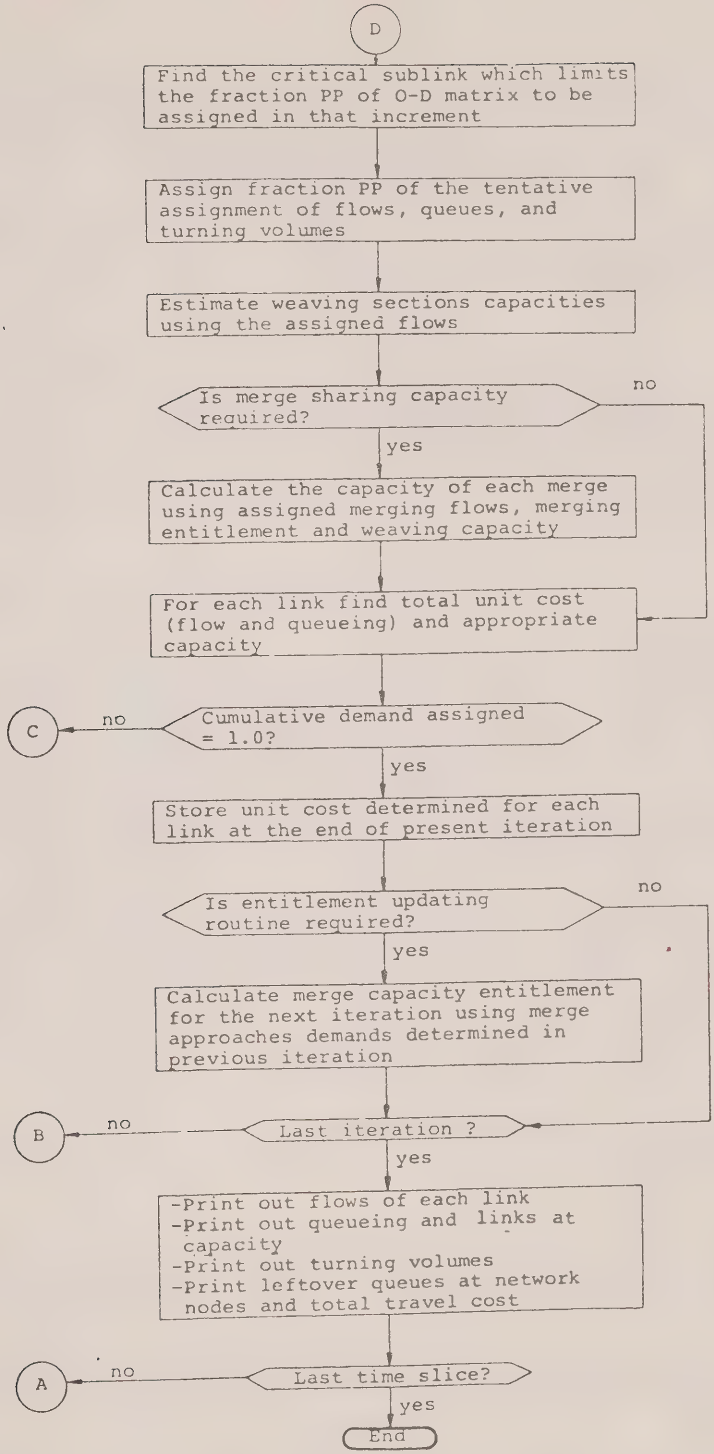

EXHIBIT 2 - (continued)

1. TITLE

EMME: An Equilibrium Based Two-Mode Urban Transportation Planning Method

2. PRINCIPAL RESEARCHER

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3. AVAILABILITY

The EMME modelling package is available in two versions, one compatible with CDC computer systems and another compatible with IBM systems. User's manuals in both English and French will be published early in 1979. Other documentation which is presently available includes numerous papers on the different components of the EMME package, papers on the coding of the road and transit networks and on the graphical outputs which can be obtained and a paper describing the application of EMME in the City of Winnipeg.

EMME can be obtained from the Centre de recherche sur les transports (CRT) of the Universite de Montreal at no charge except for copying and administration charges upon receiving approval from the Assistant Deputy Minister of Transport Canada in Ottawa. This approval is required since EMME was developed for Transport Canada and the CRT has assumed the function of acting as the repository of the modelling package.

4. MODEL DESCRIPTION

4.1 Summary Description

The EMME planning method combines a demand model (which may be a direct demand model or an O-D table coupled with a modal split function) with an equilibrium type car trip assignment and a transit assignment method. The computer model can determine equilibrium demands, flows, and service levels by considering the variable demand between the two modes as well as the interaction on the road infrastructure between private cars and transit vehicles.

* Note: A list of the contributors to project EMME is given in the Bibliography section of this documentation.

EMME was developed over the period 1976-1978 as a demonstration program of the Urban Transportation Research Branch of Transport Canada. Some of the components of the EMME model were developed and applied before this period.

The basic function of EMME is to perform a bimodal assignment on the road and transit networks of an urban transportation system. The details of this function are described in later sections. Four types of unimodal assignments may also be executed; they are:

- <u>Road Assignment with Fixed Demand</u>
  Car trips defined by an O-D matrix are assigned on a road network using an equilibrium procedure (based on an adaptation of the Frank and Wolfe algorithm for convex programming developed by S. Nguyen of the Universite de Montreal). The O-D matrix may be calculated from a total person trips O-D matrix, car occupancy factors and an estimated modal split.

- <u>Road Assignment with Variable Demand</u>
  Here the car trips and the equilibrium volumes are determined simultaneously, using a total person trips O-D matrix, car occupancy factors and modal split equations. The inter-zone transit impedances used in the modal split equations may be computed by the program or supplied by the user.

- <u>Transit Assignment with Fixed Demand</u>
  Transit passenger trips defined by an O-D matrix are assigned on a transit network using an all-or-nothing procedure, with or without diversion over common line sections. Travel times on transit links are determined from automobile times on the road network if the road network is defined. If the transit network is coded independently of the road network, then travel times are calculated from line speeds and node coordinates or are user-supplied.

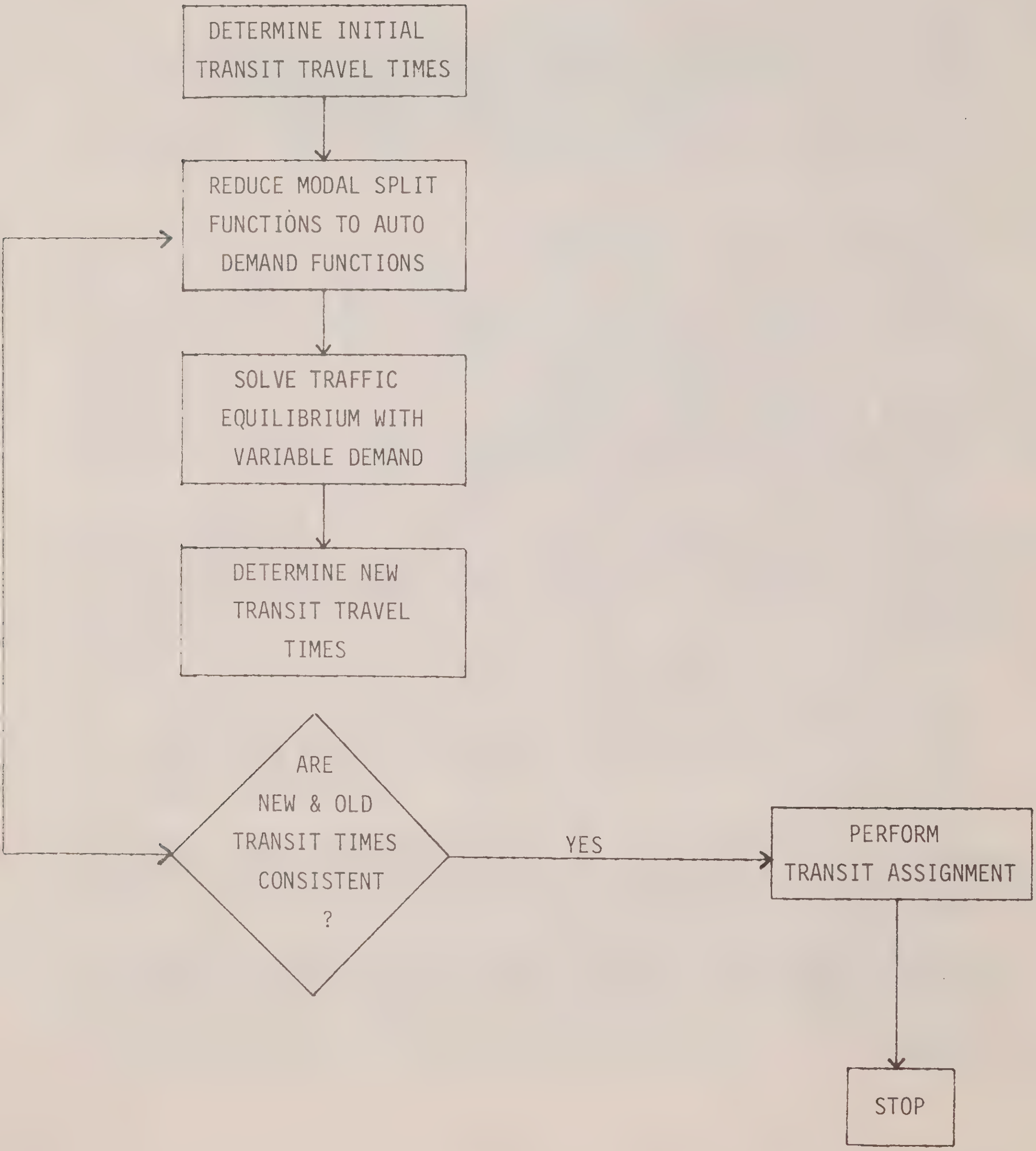
- <u>Transit Assignment with Variable Demand</u>
  The procedure is similar to the preceding one except that the transit trips matrix is obtained from a total person trips matrix and modal split equations. The inter-zone car times used in the modal split model may come from a previous road assingment or may be user-supplied.

For network design purposes, an iterative procedure that will adjust line headways to predicted passenger volumes is also included in EMME for transit assignments.

The basic computational procedure which is employed by EMME when performing a bi-modal assignment is illustrated by the flowchart diagram in Figure 1. The techniques used in the road and transit assignment components of this procedure are similar to those described under the four types of unimodal assignment.

FIGURE 1

'EMME' - THE BI-MODAL ALGORITHM



The implementation of the EMME modelling package should be within the scope of a medium-sized transportation planning department. Documentation is sufficiently detailed that outside help is not necessarily required to use the model effectively.

The development of EMME is complete and the computer package is fully operational. It is presently being used in the City of Winnipeg for the evaluation of future land-use/transportation alternatives.

4.2. Inputs Required

Three types of input data are required for the application of EMME as a bi-modal assignment procedure, road network data, transit network data, and demand data. The specific information needed from each group is given below:

Road Network Data

The road network is defined by a coded link and node network in the normal way. Links are normally classified by type and for each type a volume delay curve, which gives the travel time on the link as a function of the volume (vehicles per hour) on the link, must be calibrated from observed travel times and volumes. The link type normally implies a given free flow speed and capacity.

If the plot routines are to be used, the nodes have to be geocoded.

Data related to road links are the following:
- length
- number of lanes
- volume/delay curves
- free flow speed associated with volume/delay curves
- capacity associated with volume/delay curves
- observed volume used for the calibration of the model
- observed travel time used for the calibration of the model

Transit Network Data

The transit network is defined on a transit line basis and, for bi-modal assignments, the network must be coded to interface with the road network.

For bimodal assignments, travel times on transit links are determined from car times on corresponding road links. Therefore, a bus time/car time model has to be supplied. Such a model is obtained from an analysis of observed car times and observed transit route travel times. In the case of the application in Winnipeg, the bus time/car time model consisted of four different relationships corresponding to transit line type, which vary with the service offered (feeder, express, regular).

For transit assignments, it is not essential to relate the transit network to the road network. If it is related, then transit travel times will be automatically determined as described above. Otherwise, times will either be calculated from average line speeds and node coordinates (if geocoded) or must be supplied directly by the user.

Transit line data are the following:
- line number and name
- node sequence
- headway
- length
- speed
- type

Other useful data are observed transit travel times and passenger volumes on transit line sections.

The transit waiting times are determined by line headways.

The transit access-egress links and their corresponding walk times must be coded by the user.

Demand Data (Modal Split Equations)

The city must be divided into traffic zones that represent origin and destination for trips, each zone being identified by a number assigned to its centroid node. The size of the zones should be related to the level of detail of the networks, and should represent, as much as possible, homogenous land use activities.

Three basic O-D matrices are required:

1 - total person trips
2 - car mode person trips
3 - transit mode person trips

Other related matrices are:

4 - car occupancy matrix
5 - vehicles matrix (2 divided by 4)
6 - vehicles adjustment matrix (to take into account vehicles not included in survey data such as trucks)
7 - modal split matrix (2 divided by 1)

The demand model is an aggregated modal split function which may be a global model unique for the whole city or several models defined for different zone groups (by trip origin). The demand model is based on inter-zone times for car and transit trips and on socio-economic variables associated with the zones. In the Winnipeg application the latter variables included: proportion of males, parking cost, and car availability.

When EMME is used for estimating future levels of service on the road and transit networks of an urban area, some environmental assumptions must be made. Specifically a total person trip O-D matrix must be supplied and the values of the socio-economic variables in the modal split function must be estimated. This latter group may also include some policy variables such as parking cost.

Other policy variables which the user can specify are changes in the road and transit networks such as the construction of new road links or improvements to existing ones, and the introduction of new transit lines, or changes in the

headways of existing lines. The effects of many other policy changes could also be estimated.

A number of parameters are used in the application of EMME. Two groups of the parameters, those associated with the volume/delay curves and the bus/auto travel time functions respectively, can be estimated without the use of the assignment components of EMME. A third group of parameters, the coefficients of the modal split functions, are calibrated using the results of separate road and transit assignments carried out by EMME.

4.3 Model Calibration

An equilibrium assignment model cannot be calibrated in the same sense that a gravity-type distribution model can be; rather, inconsistencies and errors of transcription in the data that is used may be identified by careful analysis of the results.

The calibration of the road network assignment can be achieved by comparing the observed link volumes with the link volumes predicted by the traffic assignment model. The comparison is performed by using specially written programs, and manually by comparing screen line totals for the observed and predicted flows. Discrepancies between observed and predicted values may be caused by errors introduced through the total auto O-D matrix or by improper coding of the road network.

The calibration of the transit system assignment deals with the behavior of the transit passengers in the selection of paths on the network. Given the hypothesis that transit users will seek the shortest path, it is necessary to estimate the values of certain parameters of the transit path algorithm in order for it is produce satisfactory paths between the various O-D pairs.

The parameters to be estimated are:

- WFAC, a regularity factor relating the waiting time to the headway of the line to be boarded
- WMIN, the minimum waiting time
- WMAX, the maximum waiting time
- WAIT, the weight of waiting time used in the calculation of the impedance of a path in generalized time units
- WPEN, a constant penalty added to the impedance every time the passenger has to wait for the bus
- WALK, the weight of walking time (access-egress) used in the calculation of the impedance of a path

For each O-D pair the transit assignment algorithm selects the path with minimum impedance (a function of the above parameters, the access and egress times, the headways and in-vehicle times of each transit line used) from origin O to destination D. The best way to calibrate the transit model would

be to compare the predicted paths to the actual paths obtained from an O-D survey. In the Winnipeg application this data was not available, therefore, the method used consisted of analysing the predictions of a transit assignment, obtained with the observed O-D matrix, by comparing it with the observed volumes on the segments and an occasional reevaluation of the observed transit O-D matrix. The analysis was made on level of service statistics (like mean total trip time, mean number of transfers, distribution of total trip time, etc.) and on predicted line volumes. Given the all-or-nothing aspect of the assignment, only large volumes may be analysed. The following volumes were analysed:

- the volume at maximum load point of each line in both directions
- the location of the maximum load point
- volume profiles on lines
- screen line volumes
  - entering and leaving CBD
  - bridges
  - other high volume links

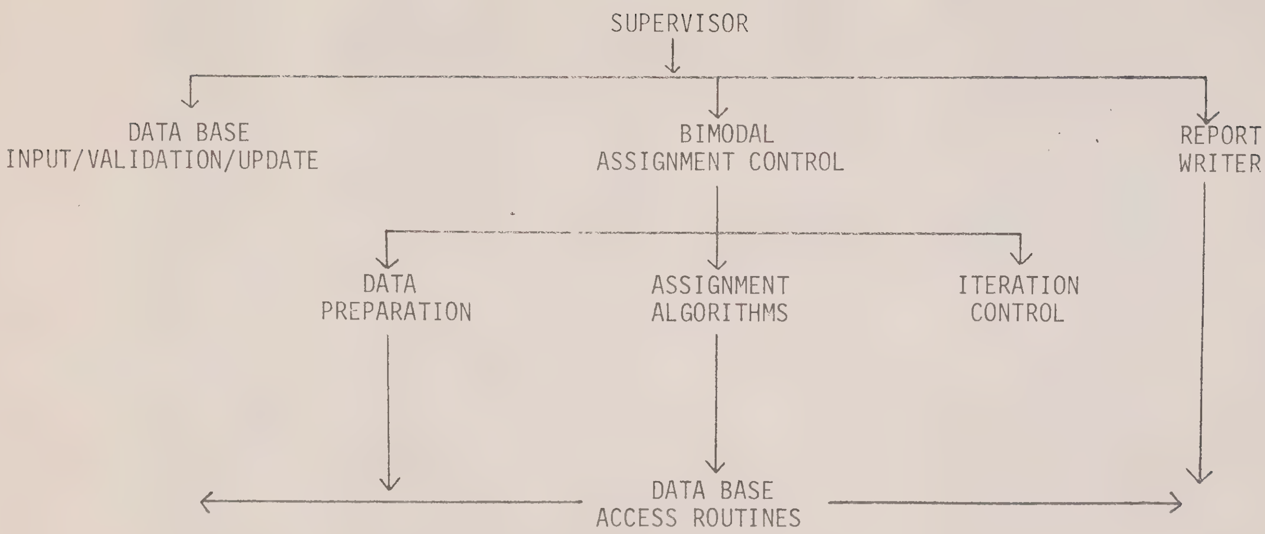
The calibration of the modal split function requires the O-D matrix of road travel times obtained from the equilibrium traffic assignment of EMME and the O-D matrix of transit impedence obtained from the EMME transit assignment component. In addition O-D matrices of distance by road and the number of transit transfers may be used. The functional form of the modal split model can be specified by the user. In Winnipeg, a logistic function using aggregate transportation system and socio-economic data was chosen. The parameters of the function were calibrated using Berkson-Theil estimation, which is simple linear regression applied to an algebraically manipulated form of the logistic function.

4.4 Model Process

When the EMME modelling package is applied, a data base containing the description of the urban road and transit networks, the socio-economic activities and the coefficients of the demand functions is first constructed. Data from the data base is then transformed into internal files that are used by EMME's assignment algorithms to predict the equilibrium demands for each mode, the link and path flows and service levels on each network.

EMME accepts a simple command language which permits the user to specify data base manipulations and request the execution of any one of the network algorithms outlined earlier. The commands are decoded by a supervisor which calls the relevant sections of the system.

The structure of the system is hierarchical, as shown in Figure 2. Within the hierarchy, the design is modular so that each section consists of a simple control procedure which calls different modules to perform the necessary functions. Well defined files provide the interface between the modules.



<u>FIGURE 2</u>: EMME: System Hierarchy

The Data Base Section includes modules to read and validate the data provided by the user. It also includes modules to transform the node numbering system defined by the user to a form which enables the network algorithms to operate efficiently. This renumbering is, however, not apparent to the EMME user.

The Bi-modal Assignment Control Section of the system calls three types of modules: data preparation modules, network algorithm (assighment) modules and iteration control modules. The data preparation modules perform demand function manipulations and transform the demand depending for instance on the auto occupancy factors. The assignment modules with their associated subroutines perform the road traffic assignment and transit assignment. During the iterative bi-modal process, communication between the two assignment modules is defined by files such as travel time by auto on each link, travel time by transit on each line segment, automobile and transit service levels (impedances) for each origin-destination pair, etc.. The iteration control modules adjust the values associated with the transit network, such as transit frequency and capacity, based on the resulting equilibrium demands, flows and service levels, and determines if another bi-modal assignment iteration is necessary. Some of the algorithms and techniques which are used during these phases of the model process have been described earlier.

When an assignment terminates, the predicted equilibrium demands, flows and service levels for each mode are saved on files which can be accessed by the Report Writer. The Report Writer modules produce reports on the predicted values. The user may also use the files containing the predicted values and the data base to produce any reports that he requires.

4.5 Model Output

The output available from the EMME model can be very extensive. Through the Report Writer modules of the EMME computer system, the user can specify which of the outputs described below he wants produced.

The major outputs of the road assignment component are characteristics of each link of the road network. These include given information such as length, type, number of lanes, free flow speed, capacity, observed travel time, observed volume, and calculated information such as predicted travel speed, travel time, auto volume and bus volume. In addition a number of global statistics may be produced, for example: total number of vehicle hours, total number of vehicle miles, average speed, average total trip time, and the distribution of total trip time.

The major outputs of the transit assignment component are characteristics of each transit line and other information such as transit levels of service on a zonal basis. The line characteristics include route name, type and headway, vehicle capacity, routing and route length which are given by the modal user, and overall and link itinerary times in both directions of the route, passenger

volumes by direction on each link, vehicle utilization, maximum load factor, and the total number of passenger minutes per hour which are calculated by the model.

The model also gives information on the number of transit trips originating from each zone, the average total trip time and the average in-vehicle, wait and walk times on both a zonal and system-wide basis, the distribution of total trip times, the number of transit passengers accessing-egressing and transfering at each of the relevant nodes in the transit network, and the number of passengers accessing and egressing from the transit network on a zonal basis.

If the road and transit network nodes are geo-coded, any one of a number of outputs can be printed in map form. Specifically, some of the outputs available in this form are: auto or transit demand by origin or by destination; modal split by origin or destination; relative differences between observed and predicted values of demand by origin or destination zone; mean trip time for either mode by origin or destination; and differences in these values between base-run conditions and alternative conditions.

Other outputs which are available if a plotter unit is used are graphical plots of predicted road travel times or volumes versus observed values.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

Both IBM and CDC versions of EMME are available from the Centre de recherche sur les transports of the Universite de Montreal. The modelling package consists of about 250 subroutines and about 25,000 fortran statements; therefore, a relatively large computer installation is required to run the model. Either tape or disk units are needed, and a plotter would be useful but is not essential.

Computer times and costs are highly dependent upon the size of the system being modelled and upon what calculations are being performed. In the Winnipeg application, the road network consisted of 1040 nodes, 2836 one-way links and 147 centroids, while the transit network had 56 lines, 1755 line segments, 500 access/egress links and 800 nodes. The computing times and the corresponding costs on the CDC Cyber 176 of the Universite de Montreal for the base year bimodal run were as follows:

	seconds
• Generate transit network	3.66
• Calculate bus frequency	1.23
• Calculate transit impedance	1110.55
• Initialize road traffic demand	3.44
• Perform road traffic assignment	2509.44
• Modify transit link times	67.61
• Calculate fixed transit demand	1.77
• Calculate demand function (transit)	0.00
• Perform transit assignment	423.91
• Modify transit capacity	0.00

Central Processor	$ 189.20
Input-Output	22.80
Fast Memory	560.40
	$ 772.40

The computing times and costs for modelling alternative scenarios would be similar in size.

5.2 Time and Staff Requirements

The use of EMME requires relatively complete data on the road and transit networks when it is applied as a bi-modal equilibrium assignment model. The principle researchers feel that EMME is best suited for application in urban areas with ongoing transportation planning programs where much of the required data would be readily available. Furthermore the effort required to calibrate the model would not be justified if the model were used for a single study only.

The transportation planning department of most urban areas should be able to calibrate and apply the model 'in-house' given that qualified staff familiar with transportation system modelling are available. The time required for the initial calibration of the model would depend upon the state of the data available, although it would likely take a number of man-months. After calibration, only a day or two would be required to model alternative scenarios. The evaluation of the results could take from a day to a week, depending upon the scope of the changes being modelled and the detail to which they were being examined.

6. APPLICATIONS

The EMME modelling package has been calibrated and validated in the City of Winnipeg and it will be used there for the evaluation of alternative land-use/transportation scenarios. The road traffic assignment component of EMME has been used in applications in England, Holland and Australia as well as in Hull and Vancouver within Canada. The transit assignment component has been applied in Montreal and has a planned application in Laval.

7. BIBLIOGRAPHY

The following publications of the Centre de recherche sur les transports (CRT) of the Universite de Montreal deal with EMME.

Florian, M. and Nguyen S. An Application and Validation of Equilibrium Trip Assignment Methods , Publication No. 28 August, 1975 (also published in Transportation Science)

Florian, M. A Traffic Equilibrium Model of Travel by Car and and Public Transit Modes , Publication No.32, December 1975 - revised July 1976 (also published in Transportation Science)

Nguyen, S, Procedures for Equilibrium Traffic Assignment with Elastic Demand , Publication No. 39, February 1976 - revised March 1977.

Achim, C., and Chapleau, R. EMME - Coding the Transit Network , Publication No. 49, September 1976

Florian, M. et al EMME: A Planning Method for Multi-Modal Urban Transportation Systems , Publication No. 62, March 177 (also published in the Proceedings of the World Transportation Research Conference, Rotterdam)

__________, Summary Report - Project EMME - Equilibre Multimodal/ Multimodal Equilibrium, Publication No. 101, June 1978

Florian, M. et at, "Validation and Application of EMME: An Equilibrium Based Two-Mode Urban Transportation Planning Method , Publication No. 103, July 1978.

In addition, publications 10, 13, 17, 18, 23, 25 and 26 of CRT deal with the initial development of the separate road and transit assignment models which are the basis of EMME.

The following is a list of the contributors to the project EMME:

Project Director	-	Michel Florian, IRO/CRT
Project Team	-	Claude Achim, CRT
	-	Robert Chapleau, Ecole Polytechnique
	-	Caroline Fisk, Ecole Polytechnique
	-	Serge Galarneau, IRO
	-	Linda James-Lefebvre, CRT
	-	Jacques Lefebvre, Centre de calcul
	-	Sang Nguyen, IRO/CRT
Staff of the City of Winnipeg	-	Ed Guertin
	-	Jarvis Kohut

1. TITLE

Dynamic Urban Systems Model for the Toronto Region

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3. AVAILABILITY OF MODEL

The 'Dynamic Urban Systems Model for the Toronto Region' should become available in mid-1979. The program has been written, the data base has been established, and model calibration is presently underway. The model structure is not specific to the Toronto region and it could be applied in different urban areas if the appropriate data were available and some modifications to the model specifications were made.

4. MODEL DESCRIPTION

4.1 Summary Description

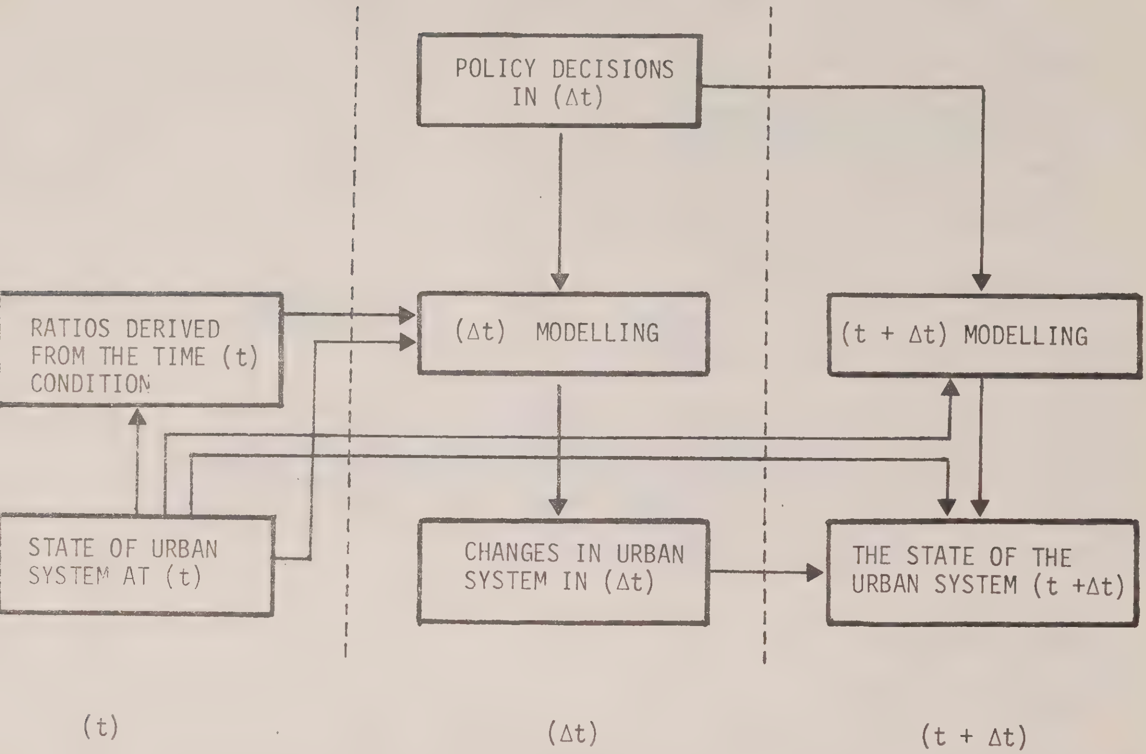
The 'Urban Systems Model' consists of activity systems, land use and transport systems sub-models. It is currently being calibrated for the Toronto region for the time period 1966 to 1971.

The model operates recursively in five year increments. The major driving force is the demand for new locations where these demands are created by migrants, re-locations, newly formed households from within the area and new employment. These demands are allocated to locations as a function of existing activity distributions and public policy actions in the land use and transport sectors. The model provides outputs on the spatial distributions of activities, the utilization of land and peak period equilibrium transport flows. The model may be used to estimate urban system responses to various public policy actions.

Figure 1 illustrates broadly the structure of the model. The state of the urban system in the base year, t, is identified along with ratios between the relevent activity magnitudes. Changes in the state of the system during Δt are then estimated as a function of time t conditions and the major public policy decisions taken in Δt. This allows the states of the system at time $t + \Delta t$ to be estimated

FIGURE 1

The Structure of the Urban Systems Model



There are ten sub-models imbedded in this structure and these are (i) basic employment, (ii) semi-basic employment, (iii) residential location, (iv) housing stock, (v) housing stock utilization, (vi) service employment, (vii) labour force, (viii job supply, (iv) transport, and (x) land accounting. These sub-models are described briefly in the section on the model process.

The model is relatively complex and so the user should have substantial experience in the calibration and application of urban transportation and land use models and some computer background.

The model is in its final stages of active development and full documentation of the Toronto application is expected to be completed by mid-1979.

4.2 Inputs Required

The state of the system at any particular time is described by the following list of variables. Historical data is required for all of these variables at two points in time. At least one of the points in time must be common across all variables. The variables include:

(i) the spatial distribution of households stratified by household type;

(ii) the spatial distributions of basic, semi-basic and population serving employment stratified by employee income group;

(iii) the spatial distribution of housing stock stratified by dwelling unit type;

(iv) the spatial distributions of the following land use categories: total land; land used by basic, semi-basic and service employment sectors; unusable land; residential land used by housing type; land available for each housing type; land available for each semi-basic employment type; and land available for each service employment type;

(v) characteristics of the transportation system consisting of a road network and a public transport network. The road network links are described in terms of distance, number of lanes and their characteristic travel time - volume properties. The public transport network is described in terms of transit lines and their associated headways, operating speed and links used.

In addition to the above data, information is required about retail activity distributions; overseas migration and household locations; and spatial interaction patterns between households and jobs.

A number of environmental assumptions need to be made and input into the model. These include: the amount of change in the overall level of basic employment; the total regional growth in five different semi-basic employment sectors; and the total regional residential growth.

The model contains a large number of policy variables which can be defined for each time increment, including: the locations of new basic employment; the locations of government subsidized housing; overseas migration policies; new transport supply investments; and, different land use zoning and servicing policies.

The number of parameters to be estimated during the calibration process is about 70 and these are listed in Table 1 for each sub-model.

Sub-Model	# of Parameters
Basic Employment	0
Semi-Basic Employment	20
Residential Location	38
Housing Stock	3
Housing Utilization	0
Service Employment	6
Job Supply	0
Labour Force	0
Land Accounting	0
Transport	8

TABLE 1

Number of Parameters to be Estimated

4.3 Model Calibration

Many of the parameters listed in Table 1 may be estimated directly from the data base using regression analysis. The behavioural parameters of the various sub-models that utilize gravity type allocation functions are being estimated using calibration techniques that are well developed in the transport and land use models areas. The outputs of the calibration process are the parameter values which define the sub-model functions.

4.4. Model Process

The model uses a dynamic process in which the future state of the urban system is estimated usingsub-model functions which incorporate the calibrated parameters and appropriate changes in policy variables. Figure 2 provides a detailed illustration of the sequence of operations within the Urban Systems Model. The ten sub-models which form part of this sequence are briefly described below:

1. Basic Employment consists of employment in heavy industry, employment in senior levels of government and mining. Change in the distribution of basic employment is an exogenous input to the model in terms of both the amount and location.

2. Semi-basic employment is allocated endogenously within the model; five types are used and these are: (i) manufacturing, (ii) construction, (iii) transportation and communications, (iv) administration, and (v) office employment. The total regional growth in each of these employment sectors is estimated exogenously and allocated endogenously as a function of zonal accessibility to households and employment and of the amount of land in the zone available for use by each type of employment.

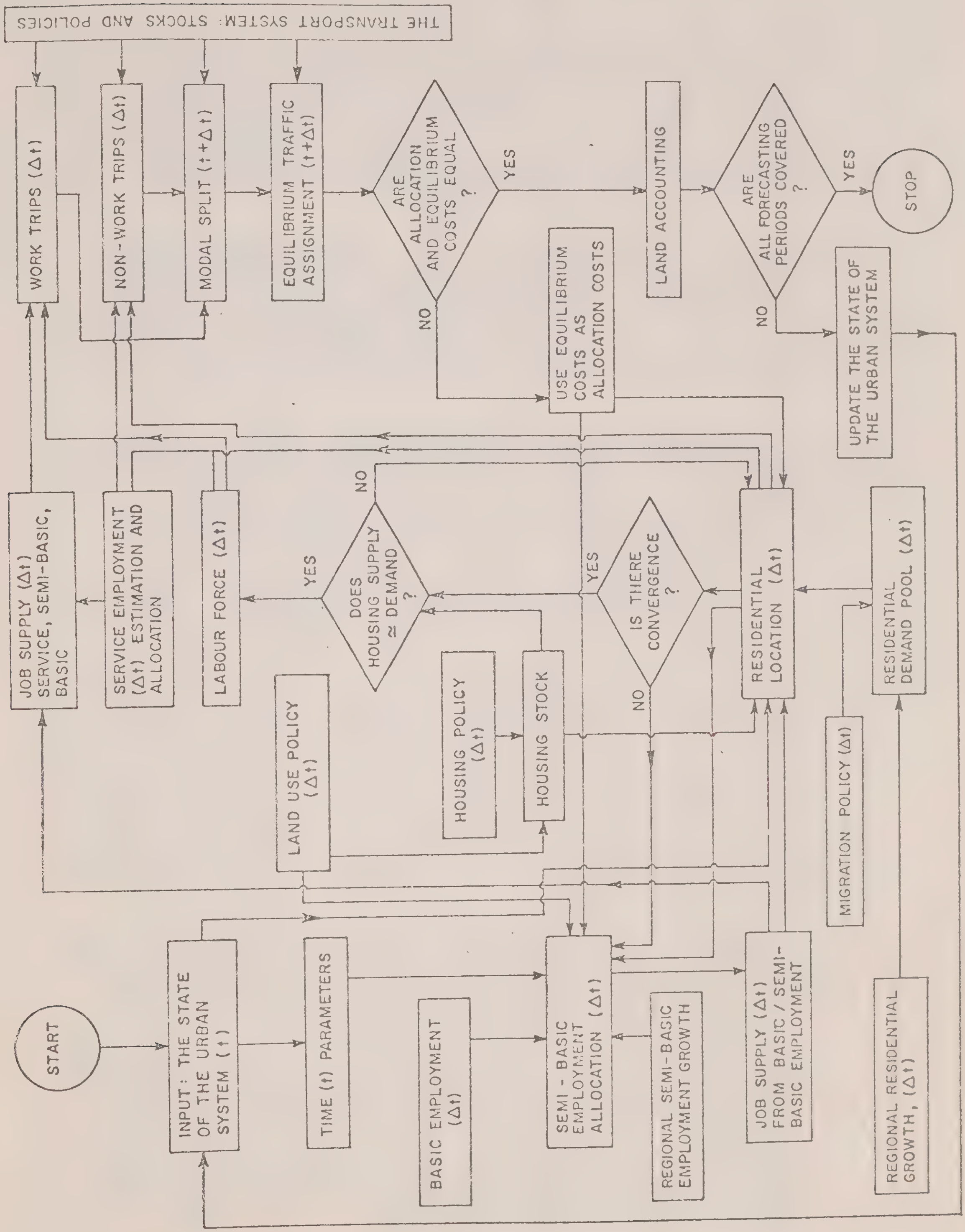
3. Residential location, the major components of household demand are: (i) shifts in household structures, (ii) new household formation, (iii) overseas migration, (iv) migration from within the region, and (v) migration from within Canada.

   The shifts in household structure within each zone at the end of each time period are functions of the total number of households of each type in the zone and the probability that households of that type will shift into household of another type during the time period. The newly formed households are estimated in a similar fashion and allocated as a function of the generalized costs of travel between zones.

   The area-wide overseas migration is specified exogenously and is allocated to the inner city residential zones by means of a function of the generalized travel cost from each zone to the CBD.

FIGURE 2

Sequence of Activities Throughout the Dynamic Urban Systems Model



Migration from within the region is related to the propensity of households to change residential locations within the region. The probabilities of moving are derived from the characteristics of the households and dwelling units such as age of household head, room occupancy levels and others. The number of households migrating from the rest of Canada to the region is an exogenous input. Both of these groups are allocated spatially in a manner similar to the allocation of newly formed households.

4. Housing stock; this submodel first estimates the total regional housing demand for each housing type as a function of the probable number of households demanding each type and the demolitions and vacancy rate of the appropriate housing type. It is assumed that the total regional demand will be satisfied within the same time period. The supply of housing is then allocated on the basis of relative accessibility.

5. Housing utilization; this sub-model balances the spatial distributions of demand for and supply of houses throughout the region within each time period. Excess demands in particular zones are allocated to unoccupied houses in other zones as a function of the spatial separation of these zones from the original zones.

6. Service employment; is classified into three types (i) retail, (ii) small business, and (iii) education employment. Estimates for each type of service employment are generated as a function of the demand rate for each type by the different household categories and the number of households in each category. The employment is allocated to the various zones on the basis of a travel cost function weighted by a measure of attractiveness of the zone for each type of service employment.

7. Labour force; the labour composition of each zone is estimated directly from the household composition of the zone. The labour force in the different income groups is a function of the probability that households of each type will have a worker of certain income group and the number of households of each type within the zone.

8. Job supply; this sub-model simply converts the employment by industry sector allocated to each zone into jobs by income group on the basis of the probability that an employee in an employment sector will be in a certain income group.

9. Transport; this sub-model estimates the travel demands associated with the new activity patterns in each area, assigns peak period trips to proposed transport networks and calculates inter-zonal travel costs. The model begins with a set of assumed travel costs and the transport sub-model calculates a new set of travel costs from the activity allocations. These new travel costs are then subtituted into the allocation process and these interactions are continued until the process converges.

The changes in work trip travel demands in each time increment are estimated using a gravit expression. The change in daily work trips between two zones of workers from a certain income group is a function of the labour force from that group residing in the origin zone and the relative value of the job supply from that income group present in the destination zone, weighted by the inter-zonal travel costs. These changes in work trip travel are combined with an initial work trip matrix and a proportion of the non-work trips to produce a matrix of peak period total trips.

A two-stage modal split model is used to split the trip matrix into trips by public transport and trips by car. Public transit captive riders are identified on the basis of income and choice trip makers are estimated using a trip disutility approach. Public transport volumes are assigned directly to the public transport network and road volumes are assigned to the road network using an equilibrium traffic assignment method by Florian and Nguyen (see Bibliography)

10. <u>Land Accounting</u>, this sub-model updates land use data at the end of each time period. The land use categories used by the model are (i) total land, (ii) land used by basic employment sectors, (iii) land used by semi-basic employment sectors, (iv) land used by service employment sectors, (v) unusable land, (vi) residential land used by housing type (vii) land available for housing types, (viii) land available for semi-basic employment type, and (ix) land available for service employment types.

4.5. Model Output

The 'Dynamic Urban Systems Model' estimates the state of the urban system at incremental points in time. The output of the model is therefore the state of the system described by:

- the spatial distributions of households stratified by household type;

- the spatial distributions of basic, semi-basic and population serving employment stratified by employee income group;

- the spatial distribution of housing stock stratified by dwelling unit type;

- the spatial distributions of land use by the categories previously listed;

- transport flows, both road and transit and generalized travel costs.

The model output is extensive and emphasis is placed on areas where activity is high.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

The 'Dynamic Urban Systems Model' is written in Fortran and is presently being run on an IBM 360/75 computer system. Either disk or tape units are required for program operation. The computer time and cost requirements for a typical run are not yet available. These requirements will depend upon the number of zones that the modelled region is divided into and upon the detail of the road and transit networks.

5.2. Time and Staff Requirements

The model uses data which is for the most part readily available. Information on the spatial distribution of households and employment for the Toronto region was obtained from Statistics Canada. The type of road and transit network data which is required is also generally available in urban areas. The extent of data manipulation required depends upon how well the available data fits into the zonal structure of the model.

A transportation planning department in any major or large urban region where the model is applicable should be able to calibrate and apply the model 'in-house'. The time required to put the model into a state where it can be used for policy testing would depend upon staff availability and the data assembled.

The effort needed to model the effect of changes in policy variables depends upon the scope and nature of the changes. The time required for these types of model runs could vary from a few days to a few weeks. The time and staff requirements for the evaluation of the results also depends upon the scope and nature of the policy decisions being modelled, and they would probably be similar to the requirements for modelling the changes to the urban system.

6. APPLICATIONS

Model calibration and policy testing is currently underway using Toronto Region data.

7. BIBLIOGRAPHY

Said, G.M. and Hutchinson, B.G. "An Urban Systems Model for the Toronto Region", Proceedings of the Second International Symposium on Large Engineering Systems, University of Waterloo, May 1978

Said, G.M., "Proposed Model Structure and Equation System" Working paper No. 4, Transportation Group Department of Civil Engineering, University of Waterloo, June 1977

1. TITLE

METRANS: An Interactive Transportation/Land Use Gaming Model for Metropolitan Toronto

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3. AVAILABILITY OF MODEL

The METRANS model can be obtained from the University of Toronto/York University Joint Program in Transportation at no charge except for copying costs. The model structure has been documented and a user's manual has been written. (see Bibliography). METRANS can be used without modification as a simulation game for the planning of transportation systems and related urban development in Metropolitan Toronto. The model could be applied to other municipalities, although this would require extensive recoding of both the base data and some parts of the computer program.

4. MODEL DESCRIPTION

4.1 Summary Description

METRANS is an interactive gaming simulation model, written in APL, which educates the players of the game as to the types of decisions required in planning for Metropolitan Toronto's transportation system and provides a method for testing the effectiveness of alternative transportation/land use decisions.

METRANS had its beginnings in the 1972-73 academic year, at which time Professors Found and Rice offered a joint graduate course at York University and the University of Toronto. The course, sponsored by the University of Toronto/York University Joint Program in Transportation, was designed to attract graduate students from a number of disciplines, and to introduce them to prevalent gaming techniques set in an urban transportation context. Since 1972-73 the game and computer model have been utilized in several university courses, and have undergone a number of improvements and modifications.

In METRANS game players simulate the planning of Metropolitan Toronto in a simplified, but realistic, replication of planning in the real world. Realism in the planning process is achieved by dividing the game players into groups which approximate the agencies which actually make transportation and related decisions for Metropolitan Toronto. Detailed data

from 1964, the one year in which comprehensive data are available for Metro, are utilized as the starting point for the gaming simulation. The general procedure is for the game to begin with the presentation of the real-world situation in 1964, and for game players to introduce planning changes in a number of steps in the years to follow. The impacts of these planning decisions are determined by using a computer simulation program, which is designed to predict the likely impacts of planning decisions on such features as traffic flow, and population and employment distribution. The computer program utilizes a number of forecasting techniques, and has proven to generate predictions which appear to be quite feasible.

The program contains four component models as follows:

(i) <u>a transportation system performance model</u>, which permits the estimation of link volumes and travel times by mode through the use of the standard four-stage sequence of trip generation, distribution, modal split and assignment,

(ii) <u>a land-use growth model</u>, which allocates total metropolitan population and employment changes to the sixteen planning districts in accordance with zoning ordinances, zonal capacity, and transportation accessibility,

(iii) <u>an environmental impact model</u>, which determines the environmental effects of changes to the transportation system, and,

(iv) <u>a budgetary and fiscal model</u>, for estimating the budgetary requirements of transportation improvements and the implications of these expenditures on municipal taxation levels.

Each of these components will be described in greater detail in section 4.4 Model Process.

As was stated earlier, the model is written in APL, an interactive programming language. Furthermore, all model input and output is transmitted to the computer via a standard typewriter terminal. This makes the model quite easy to use, and the game can be played by people with no computer background and limited experience in transportation planning.

Although the model is no longer under active development, some modifications to the computer program are made periodically. METRANS is currently being used on a regular basis in courses at the University of Toronto and York University.

<u>4.2 Inputs Required</u>

When METRANS is used without modification as a simulation gaming model of the transportation/land use system in Metropolitan Toronto, the only inputs required are policy variables from three different classes.

The specific changes which can be made within each class are listed below:

1) zoning variables

- modifications to the ratio of different types of new construction in each planning district. There are three types of construction possible: high density or apartment buildings, intermediate density or single attached homes, and low density or single detached homes;

- modifications to the maximum allowable density overall for each planning district (people/acre);

- demolition of existing housing by type for each planning district;

- annual growth rate for manufacturing employment (percent) for each planning district.

2) road network characteristics

- modifications can be made to upgrade an existing link to a higher status (road links are classified as 'local', 'arterial', or expressway')

- the number of lanes of an existing link can be increased;

- a completely new link can be added to the network.

3) transit network characteristics

- an existing link can be upgraded to a higher status (transit links are classified as 'walk', 'surface', and 'subway'. In addition a new link type, 'intermediate' can be introduced)

- the headway can be modified on a specified link

- a new link can be added to the network

- subway train length can be modified

In order to be applied in another municipality, fairly extensive cross-sectional historical data would be required including demographic information and transportation system characteristics. In addition some environmental assumptions such as the overall population growth rate and the costs of implementing transportation system changes would have to be made. More complete information on what the requirements would be for using the model in a different setting can be obtained from the principal researchers.

4.4 Model Process

The METRANS game begins with an examination of the situation in Metro Toronto in 1964. The data for the inital situation are available in three forms: (a) tables; (b) a highly generalized map subdivided into Metro Toronto's sixteen planning districts, and (c) very detailed maps of road and public transit links throughout the Metropolitan area. METRANS can be played within a variety of time settings, but the preferred operation is to play the game over the period 1964-1984.

The normal sequence for a specific time period is for the player groups to first request data from the computer relating to various aspects of Metropolitan Toronto during the current time period. Once discussions have been completed and 'Metro Council' has decided on a provisional set of decisions, the computer is fed the planning changes and the resultant costs are calculated. The players then have an opportunity to alter their planning decisions should that seem advisable. The sequence continues until the Council is satisfied that proper planning decisions have been made. At this time the computer model generates the changes in the status of the many variables in the model for the situation at the end of the planning period, assuming that the recommended planning changes have been implemented. The players then have the opportunity to request various types of output information to assess the impacts of the planning changes. The output should enable them to plan changes for the next time period, or to revise and re-run the current time period.

Figure 1 is a generalized flow diagram which indicates the major characteristics of the operation of the computer model. Figure 2 is a flow chart of the simulation model operation. The model components in which calculations are performed are listed below:

a) Residential growth allocation

- the increase in population for the total region is allocated to each zone on the basis of the relative accessibility of each zone to employment opportunities in the region

b) Employment growth allocation

- service employment growth is allocated on the basis of accessibility to population
- manufacturing employment growth is a policy variable

c) Trip generation and attraction

- linear functions of population and employment respectively
- trip attractions are normalized to equal trip generations

d) Trip distribution

- interzonal trips are calculated using an iterative procedure in which trips are a function of trip generations, trip attractions and a conductance matrix

FIGURE 1: Generalized METRANS Computer-Model Operation

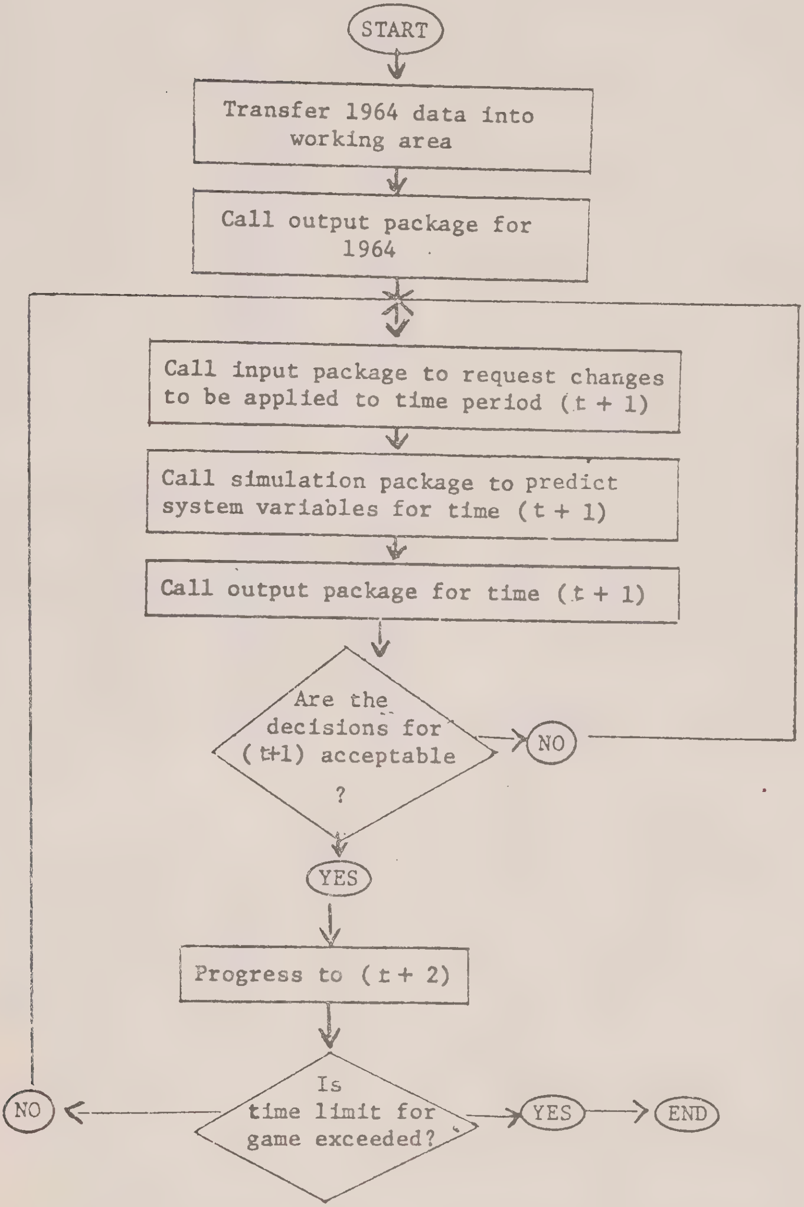
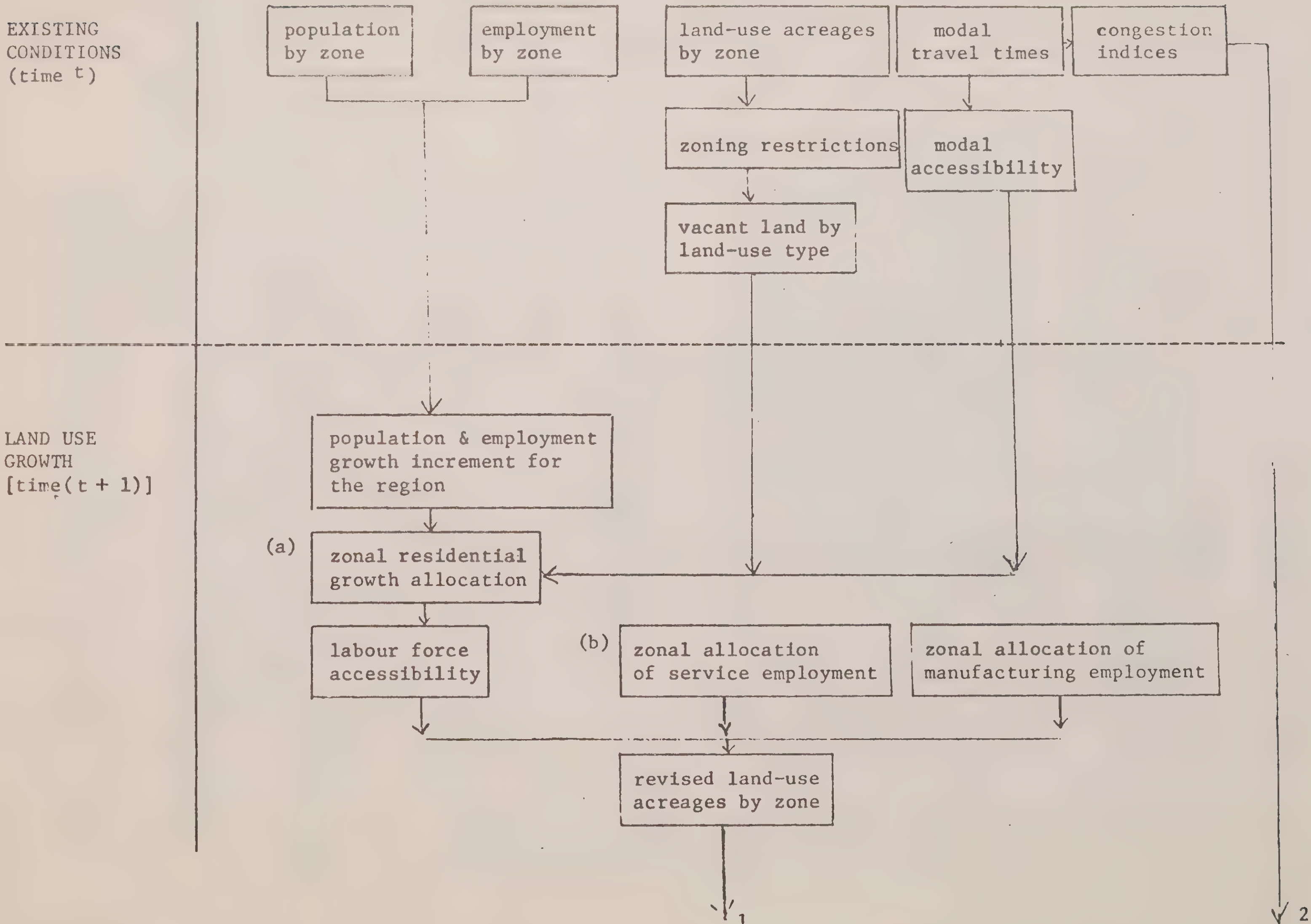
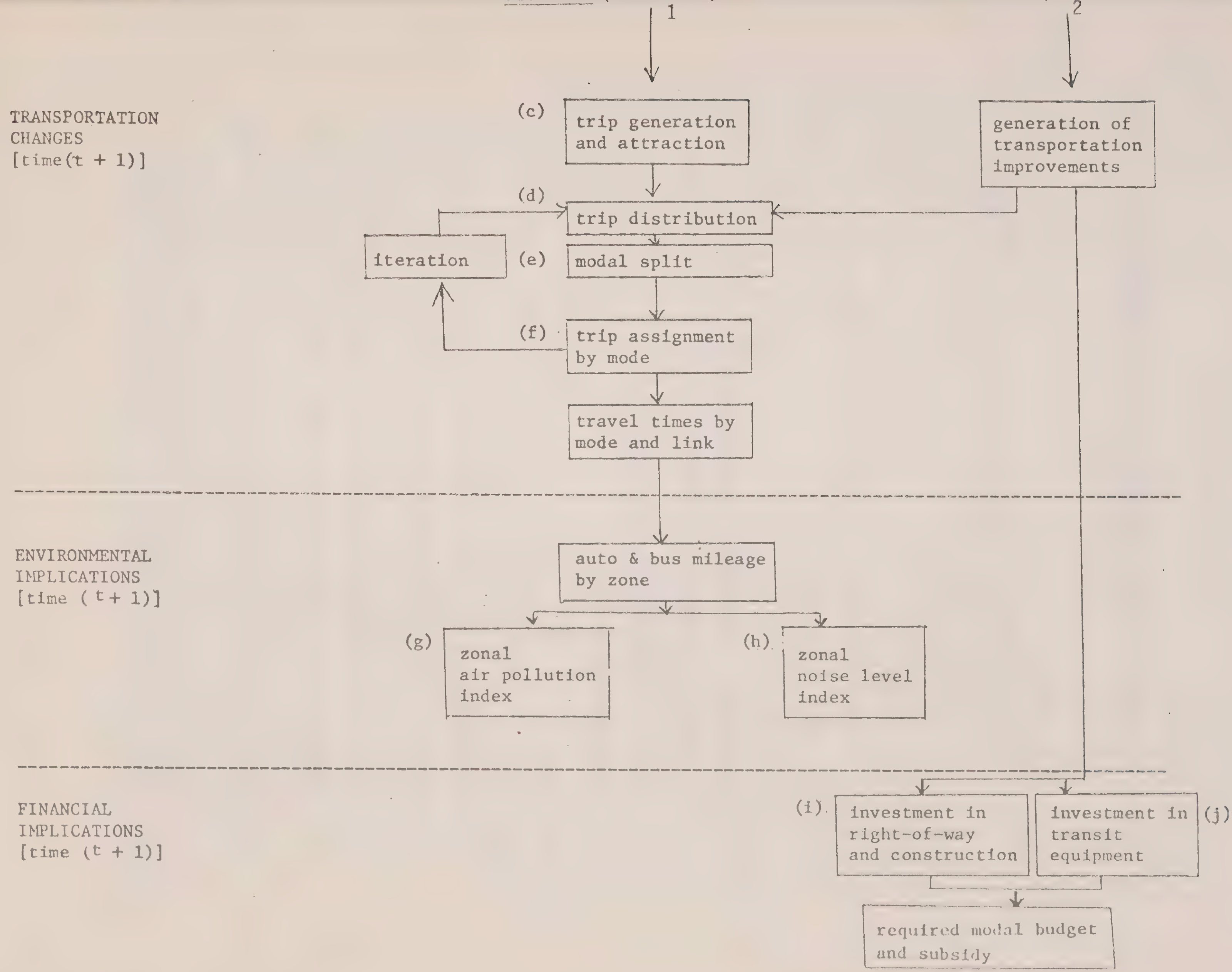


FIGURE 2 - FLOW CHART OF THE METRANS SIMULATION MODEL OPERATION



(continued)

FIGURE 2 (continued)



e) Modal split

- calculated using an iterative procedure; percent by transit is a function of interzonal travel times and volume

f) Trip assignment

- trips are assigned to both the road and transit networks using an iterative capacity restraint technique. Moore's algorithm is used to calculate the minimum paths for the initial iteration.

g) Air pollution index

- a linear function of car-miles and bus-miles

h) Noise level index

- as above

i) Transportation right-of-way and construction cost

- linear functions of route miles

J) Required investment in transit equipment

- as above

4.5 Model Output

The computer model has four types of output:

(1) selected demographic data indicated on a small zonal map

(2) outputs of selected link characteristics on a large map (one each for road and transit networks);

(3) lists of selected link characteristics in tabular form, and

(4) tables which list specified inter-district flows, travel times, etc.

The first type of output can provide data for 26 different variables (Table 1). Up to four data sets may be displayed on any one map.

Several types of data can be displayed on the large map output (see Table 2 for a list of the types of data that can be displayed). In addition to indicating numbers for specific links, the map output package can highlight particular link characteristics through use of special symbols chosen by the terminal operator.

METRANS

TABLE 1 VARIABLES FOR WHICH DATA ARE AVAILABLE AT THE LEVEL OF THE INDIVIDUAL PLANNING DISTRICT

Variable	Units of Measurement
1. population	1000's of people
2. employment	1000's of jobs
3. apartments	dwelling units
4. single attached homes	dwelling units
5. single detached homes	dwelling units
6. vacant land	acres
7. zoned density	persons/acre
8. zoned percent new apts.	percent
9. zoned percent single attached homes	percent
10. zoned percent single detached homes	percent
11. housing density	persons/dwelling unit
12. population density	persons/acre
13. vehicle density	vehicles/dwelling unit
14. ave. car commuting time	minutes
15. ave. transit commuting time	minutes
16. car riders	number
17. bus riders	number
18. car traffic in district	car miles
19. bus traffic in district	bus miles
20. population growth	percent
21. employment growth	percent
22. air pollution	index (100 in 1964)
23. road construction	new units
24. noise	index (100 in 1964)
25. money spent	1000's of dollars
26. air pollution assuming techological change in engines	index (100 in 1964)

METRANS

TABLE 2 DATA THAT CAN BE DISPLAYED ON THE ROAD AND TRANSIT LINK MAPS FOR EACH LINK

Variable	Unit
1. load	100's people/hr.
2. travel time	10 x minutes
3. volume/capacity	ratio x 100
4. speed	m.p.h.
5. length	10 x miles
6. type	nominal
7. lanes/hwy.	number
8. district	nominal
9. node from	number
10. capacity	100's people/hr.

Link data such as volume, travel time, volume/capacity ratio and capacity are available in tabular form; however, it has been found that these may be viewed most usefully in map form. The interzonal data which are in matrix format are the following:

- interzonal volume, both modes
- interzonal volume, by road
- interzonal volume, by transit
- interzonal travel times, both modes
- interzonal trave times, by road
- interzonal travel times, by transit

These have been proven to be difficult to interpret and are not widely used.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

METRANS is programmed in the APL language and is accessed by telephone using a typewriter-style computer terminal. The programming mode is conversational. The software and data are stored in 12 "workspaces" (80 tracks) on disk on an IBM 370 computer at the University of Toronto.

For a typical twenty year simulation involving five separate sets of planning changes throughout that time period the CPU time is approximately 15 minutes while the terminal connect time in a little over 6 hours. The total cost for a run such as this would be about $100.00.

5.2 Time and Staff Requirements

The requirements in terms of staff and time needed to run the model as is are minimal. When used as a gaming model, five teams are needed; however any of the teams can consist of a single player.

In a typical gaming situation, a twenty-year run would take six hours or more, depending upon how argumentive the game players are. Since most of the model output is presented in map form, the interpretation of the results is relatively straightforward.

No estimate was made of the time and staff requiremetns needed to apply this model to a different municipality. The model generally uses standard demographic and transportation data, and it is possible that a good portion of the model structure could be kept intact. However, the requirements for the calibration and testing of a revised model could be substantial.

6. APPLICATIONS

As stated earlier the model has been applied in a number of courses at both the University of Toronto and York University. The model is based on real-world data collected in Metropolitan Toronto.

7. BIBLIOGRAPHY

R.G. Rice, et al, An interative Transportation Gaming Model for Metropolitan Toronto, Research Report No. 17, University of Toronto/York University Joint Program in Transportation, April 1974

W.C. Found and R.G. Rice, METRANS: Manual for a Simulation Game for Transportation/Land-Use planning in Metropolitan Toronto, Research Report No. 40, University of Toronto/York University Joint Program in Transportation, April 1977

R.G. Rice, Transportation Plan Evaluation as a Continuous Process: A Proposed Framework and Case Study published in Annual Conference Preprints, RTAC, 1977

1. TITLE

Truck Routes and Terminal Consolidation Model

2. PRINCIPAL RESEARCHER

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3. AVAILABILITY OF MODEL

The completed program is available to any potential user on a cost basis, i.e. cost of tape plus machine copying charges. To obtain a copy contact the principal researcher. A comprehensive user's manual may be available from Transport Canada as they funded the original research.

4. MODEL DESCRIPTION

4.1 Summary Description

As indicated in the title, there are two components of truck fleet operations rationalized in this model, namely the consolidation of (1) truck routes, and (2) terminal operations. The model was developed with funds from the Transportation Research Centre of Transport Canada as part of their "Urban Trucking Rationalization Study".

The overall objective of the model is to generate the most efficient truck operating network. The model calculates the number of vehicles and the associated costs required to efficiently carry a given set of consignments throughout a city divided into N zones and partitioned into an inner city (IC) and an outer city (OC) set of zones. An optimizing procedure compares the costs of either interposing a consolidation terminal or using direct routing for IC-OC and OC-IC links (note that for traffic within the sets of zones, IC-IC and OC-OC, a consolidation terminal is not an available option).

The model, written in FORTRAN, is interfaced with a simpler language called FLECS which greatly facilitates the use of the program. Thus, most traffic engin-ers and planners should be able to use this computer package. Presently, the model is not undergoing any changes and is available in its final form.

4.2 Inputs Required

The input data consists of three distinct categories: (1) O-D matrices, (2) zone and vehicle data, and (3) terminal cost function.

1. O-D Matrices

   - demand for freight (lbs.)
   - number of consignments
   - trip times
   - pick-up times
   - delivery times

2. Zone and Vehicle Data

   - The number of zones, including a terminal, if there is one.
   - The number of inner city zones, including a terminal, if there is one.
   - The zone number of the terminal, if there is one. The terminal has its own zone number, with no initial demand.
   - To determine if a route consolidation run is to be made (=1 if yes, a consolidation run is to be made; =0 if not)
   - To determine if a new cost function is to be read in (=1 if yes, a new cost function is to be read in; =0 if not).
   - Capacity of the small vehicle, in lbs.
   - Capacity of the large vehicle, in lbs.
   - Effective vehicle capacity ratio for a link with a terminal at one end.
   - Effective vehicle capacity ratio for a non-terminal link.
   - The number of hours of vehicle operation per day.
   - The 'time split' in hours. For zones less than TSPLIT apart, the number of round trips can be incremented if the load factors are exceeded. For zones greater than TSPLIT apart, the larger size vehicle can be substituted if the load factors are exceeded.
   - The driver turn-around time at the terminal, in hours.
   - Capture iteration parameter: when the largest change in captured demand is less than TEST, we have obtained the 'optimum' solution and iteration is discontinued.
   - Capture iteration parameter: when the number of cycles equals ITEST, the present capture is output as the 'optimum' solution.
   - The standby cost of the small vehicle, in dollars per hour.
   - The operating cost of the small vehicle, in dollars per hour.
   - The standby cost of the large vehicle, in dollars per hour.
   - The operating cost of the large vehicle, in dollars per hour.

3. Terminal Cost Function

- The number of points defining the terminal cost function, including the point at zero volume (must be $\leq$ 16).
- The daily terminal through-flow in lbs. at the NPTS, or last, data point (VTMAX).
- The constant terminal through-flow in lbs. before any capture from the demand matrix.
- First point of dependent variable defining terminal cost function, in $/lb., at Volume = 0 lbs.
- Second point of dependent variable defining terminal cost function, in $/lb., at Volume = VTMAX/(NPTS - 1).
- Ith point of dependent variable defining terminal cost function, in $/lb., at Volume = VTMAX*(I-1/(NPTS - 1).
- The last point of dependent variable defining terminal cost function, in $/lb., at Volume = VTMAX.

4.3 Model Process

The program ROUTES consists of a set of Internal Procedures which are listed in Exhibit 1. Each Internal Procedure refers to an element of the overall model process. The process is described below and some of the more important procedures are also briefly discussed.

A number of matrices are transmitted into the model as input and are echoed out at execution time. These matrices include:

- a matrix of the demand in lbs. from zone to zone
- a matrix of the number of consignments from zone to zone
- a zone to zone trip time metrix
- pick-up and delivery time metrices

An average weight matrix is calucated by the program. A capture matrix is also calculated. In a run with a consolidation terminal, it reflects the fact that movements of consignments between zones and in the Inner City (IC) and the Outer City (OC) (excepting a terminal which has no inherent demand) are considered to be captured by the terminal. Later on the capture matrix may be altered according to the cost comparison between terminal and non-terminal routings for the consignments.

In the next step, details for route consolidation with a terminal are calculated and printed out using the "COMPUTE-ROUTE-DETAILS" Internal Procedure. The various details which are calculated are shown in Exhibit 2. Following the route details, three summary tables of the breakdown of time are calculated for small vehicles, large vehicles and all vehicles. An example of one of these tables is shown in Exhibit 3.

EXHIBIT 1

INTERNAL PROCEDURES CROSS-REFERENCE TABLE

CALCULATE-AVERAGE-CONSIGNMENT-WEIGHTS
COMPUTE-CELL-COSTS
COMPUTE-ROUTE-COSTS-AND-SUMMARY
COMPUTE-ROUTE-DETAILS
COMPUTE-TERMINAL-UNIT-COSTS
FORMAT-INPUT-AND-OUTPUT
HANDLE-INTRA-ZONAL-ROUTING-WITH-WATERFALL-ALGORITHM
INCREASE-NO-OF-VEHICLES-SO-THAT-LFMAX-IS-1
OUTPUT-SUMMARY
ROUTE-WITH-INCREASED-NO-OF-ROUND-TRIPS
SELECT-LOWEST-CELL-COSTS-AND-COMPUTE-CAPTURE
SET-UP-ROUTING-SCHEME
SKIM-OFF-REMAINING-INTRA-ZONAL-TRUCK-DAYS
SUM-OVER-ALL-INNER-CITY-NODES
SUM-OVER-ALL-OUTER-CITY-NODES
TRUNCATE-FLEET-AND-REDUCE-DEMAND
WRITE-CELL-COSTS
WRITE-OUT-SYSTEM-PARAMETERS
WRITE-ROUTE-DETAILS

EXHIBIT 2

SAMPLE OUTPUT FOR ROUTE AND TERMINAL CONSOLIDATION PROGRAM

ROUTE DETAILS:

ROUTE NO.	ZONE (I)	ZONE (J)	NO. OF TRUCKS	NO OF ROUND TRIPS	TRUCK COSTS ($)	LARGE TRUCKS ?	TOTAL MOVEMENT OF GOODS (LBS)	MAX. LOAD FACTOR	MIN. LOAD FACTOR	INTER-ZONE MOVEMENT I-J(LBS)	INTER-ZONE MOVEMENT J-I(LBS)	INTRA-ZONE MOVEMENT I-I(LBS)	INTRA-ZONE MOVEMENT J-J(LBS)
1	2	1	16	1	1663.	NO	60200.	0.59	0.59	30000.	30000.	0.	200.
2	4	1	11	1	1146.	NO	20500.	0.40	0.40	10000.	10000.	600.	200.
3	4	2	18	2	1876.	NO	180300.	0.79	0.79	90000.	90000.	300.	0.
4	6	1	11	1	1148.	NO	20000.	0.39	0.39	10000.	10000.	0.	0.
5	6	2	21	3	2197.	NO	240800.	0.60	0.60	120000.	120000.	800.	0.
6	6	4	12	2	1253.	NO	62800.	0.56	0.56	30000.	30000.	1600.	1200.
7	3	2	16	2	1690.	NO	160000.	0.78	0.78	80000.	80000.	0.	0.
8	7	2	15	1	2091.	YES	160000.	0.33	0.33	80000.	80000.	0.	0.
9	7	3	11	3	1160.	NO	102200.	0.66	0.66	50000.	50000.	1200.	1000.
10	5	2	15	1	2091.	YES	160000.	0.33	0.33	80000.	80000.	0.	0.
11	5	3	10	1	1387.	YES	101200.	0.43	0.43	50000.	50000.	700.	500.
12	5	7	11	3	1160.	NO	122600.	0.79	0.79	60000.	60000.	1400.	1200.
13	1	1	4	3	416.	NO	8000.	1.00	1.00	0.	0.	8000.	0.
14	4	4	4	3	416.	NO	23700.	1.00	1.00	0.	0.	23700.	0.
15	6	6	4	3	416.	NO	31600.	1.00	1.00	0.	0.	31600.	0.
16	3	3	4	3	419.	NO	44000.	1.00	1.00	0.	0.	44000.	0.
17	7	7	4	3	419.	NO	52800.	1.00	1.00	0.	0.	52800.	0.
18	5	5	4	3	419.	NO	61600.	1.00	1.00	0.	0.	61600.	0.

TO PICK UP THE REMAINING 11800.00 LBS. OF FRACTIONAL-VEHICLE-DAYS IN THE INNER CITY, A FLEET OF 3 TRUCKS IS ROUTED THROUGH THE ZONES, FOR A TOTAL COST OF $ 308.32 .

TO PICK UP THE REMAINING 15600.00 LBS. OF FRACTIONAL-VEHICLE-DAYS IN THE OUTER CITY, A FLEET OF 2 TRUCKS IS ROUTED THROUGH THE ZONES, FOR A TOTAL COST OF $ 204.64 .

EXHIBIT 3

SUMMARY TABLE OF TRAVEL TIMES

SUMMARY BREAKDOWN OF TIMES (IN %) OF THREE SUB-GROUPS INTO EIGHT CATEGORIES FOR ALL VEHICLES:

SUB-GROUP	STOPPED TIMES(RATIOS OF SUB-GROUP TIMES IN %):					DRIVING TIMES:		
	WHILE DOING INTRA-ZONAL P&D	WHILE DOING INTER-ZONAL P&D	TURN-AROUND TIME AT TERMINAL	IDLE TIME	ALL STOPPED TIME	WHILE DOING INTRA-ZONAL P&D	WHILE DOING INTER-ZONAL P&D	ALL DRIVING TIME
INNER CITY(IC)-IC (101.0 VEHICLES) (808. HOURS)	6.3	37.1	3.6	0.9	47.9	6.3	45.8	52.1
OUTER CITY(OC)-IC (49.3 VEHICLES) (395. HOURS)	2.3	36.5	4.0	1.3	44.1	2.3	53.7	55.9
OC-OC (46.0 VEHICLES) (368. HOURS)	13.0	26.1	0.0	3.0	42.1	16.3	41.6	57.9
TOTALS (196.3 VEHICLES) (1571. HOURS)	6.9	34.4	2.8	1.5	45.6	7.6	46.8	54.4

TOTAL OF TRUCKING COSTS= $ 21879.99

On the basis of information contained in the route details and the summary tables, matrices of the terminal costs, trucking costs, and total costs for each zonal pair are calculated. The Internal Procedure "COMPUTE-CELL-COSTS" is used in this step.

The costs of route consolidation with a terminal are now know, and the terminal part of the run is complete. Next the route details for route consolidation without a terminal are calculated. Again the route details are followed by three summary tables which breakdown the travel time into eight categories. (as shown in Exhibit 3).

The route consolidation cell (or zonal pair) costs are then compared with the terminal consolidation costs. If for a specific Inner-City Outer-City pair of zones the former costs is less than the latter, the capture matrix is changed and consignments between those zones no longer go through a consolidation terminal. As the captured volume is reduced the unit costs of goods processed at the terminal are increased. This in turn increases the terminal consolidation costs for those zonal pairs still using the terminals. The new costs are compared as before to the route consolidation costs in an interative procedure. At the end of this procedure the final cell costs are written out as is the associated capture matrix.

4.4 Model Output

The program output provides route details including:

- the link,
- number of trucks and round trips,
- trucking costs (not including terminal costs),
- truck size,
- load factors, and
- weight of consignments carried (see Exhibit 2)

It also produces summary tables of vehicle operating times for various link combinations of IC and OC and for small, large and total trucks (see Exhibit 3). All costs corresponding to the demand matrix are also printed.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

The program is written in FORTRAN with the FLECS language used to run ROUTES and generate the appropriate solution. Thus, the user will have to have access to a computer installation with a FLECS compiler. For most problems storage will not be a major problem: the requirement is roughly $7N^2$ plus program code, where N is the number of zones. With N=35 a typical run would cost around $10.00.

5.2 Time and Staff Requirements

The O-D data matrices for urban trucking are certainly time consuming and expensive to collect while the remaining parameters require an in-depth knowledge of urban trucking operations and costing. The costs of collecting O-D information could be reduced if these movements were surveyed at the same time as automobiles.

Running the model is relatively straight forward given the use of FLECS which automatically handles the clerical work in the program. The interpretation of the results is also straight forward and consequently the staff requirements are small.

6.0 APPLICATIONS

Up until now the model has only been used in an illustrative capacity for the Vancouver case study.

7.0 BIBLIOGRAPHY

Transportation Research Centre, 1977, Truck Routes and Terminal Consolidation Model, Montreal, Quebec

1. TITLE

MICRO Model - URBGDS Model Package.

2. PRINCIPAL RESEARCHER

N.D. Lea and Associates
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3. AVAILABILITY OF MODEL

The MICRO model was developed by N. D. Lea and Associates for the Urban Transportation Research Branch of Transport Canada, and should be available from either organization. The model structure is documented in a report prepared by N. D. Lea and Associates, but a comprehensive user's manual is not available. Since the model computer program is written in the GPSS programming language, changes in the input data must be made within the program itself. Therefore the model cannot be used 'off-the-shelf' and must be adapted for each application.

4. MODEL DESCRIPTION

4.1 Summary Description

The MICRO model is a queuing model, written in the GPSS simulation language. The model was developed in 1972 as part of an urban goods movement modelling package. The other component of the package, the MACRO model, is a network assignment model in which goods and vehicles are routed over the network using either minimum time or minimum cost criteria.

The basic function of the MICRO model is to simulate the goods transfer operations at a single "endpoint." An endpoint is a particular geographical location (usually a building) in the urban area where goods are picked up and/or delivered, or transferred from one vehicle to another. An endpoint may or may not have "facilities". A facility is some combination of structures and/or equipment which have been specifically provided to effect the goods P & D or transfer operation. By appropriate selection of input parameters, six types of endpoints can be simulated by the MICRO model:

No facility (curbside operation)

Laneway without dock

Laneway with dock

Yard only

Off street dock

Yard and dock.

Any type of endpoint in the city from a private home to a long haul terminal can be classified into one of these six types and simulated. The MICRO model was designed to simulate average or typical endpoints of each of the six types in different zones with various land use characteristics. It can also be used to simulate a specific endpoint.

The model operates on the basis of time and keeps track of all trucks in the vicinity of the endpoint from their arrival time to their departure time. Time to perform operations and delays due to the presence of other trucks are accounted for. Where decisions must be made, probabilities of certain courses of action are assigned and the model makes its decisions on the basis of these probabilities. Usually a random number is generated for the given probability distribution; its value then determines the decision made.

Although the MICRO model is not complex, knowledge of the GPSS simulation language would be required since the program documentation is limited. The development of the model was completed in 1972, and after an initial application using data collected in Calgary, no further major work was performed.

4.2 Inputs Required

The following inputs are required for the application of the MICRO model:

1. Truck arrival rate - this is given as a mean number of minutes between vehicles and a range. The model creates an arrival by picking a uniformly distributed random number over the range. Empirically derived arrival rates can also be input.

2. Pickup and/or delivery distribution - the specification of the percentage breakdown of arrivals which are: pickups, deliveries, and both.

3. Shipment weight distribution - the frequency distribution is specified as a curve.

4. Number of pieces per shipment distribution - the frequency distribution is specified as a curve.

5. Truck departure #1 - given as a function of the shipment weight. Above this weight the truck will stay; below this weight the truck will leave, only if all docks are full.

6. Truck departure #2 - given as a percent that will leave if no legal parking is available. This is dependent on time period and area.

7. Loading and unloading time - given as a function of the shipment weight and amount of men and equipment available for loading/unloading.

8. Manoeuvring time - given as a time figure for each vehicle type.

9. Shipment preparation time - specified as a probability that the driver will wait for a shipment to be prepared.

10. Signature time - given as a function of the number of pieces in the shipment.

11. Time to find agent - given as the mean of a Poisson distribution.

12. Signature first probability - percent of vehicles that obtain signature first before unloading (of those that park on the street).

13. Third party costs - given as a table of minutes of truck illegal parking (blocking a traffic lane) vs. minutes of passenger delay for peak or off-peak conditions.

14. Walking speed - given as feet/minute.

15. Legal, illegal and yard parking area sizes.

16. Walking distances from legal, illegal and yard areas.

17. Number of docks.

18. Number of men in addition to driver to load or unload.

19. Time length of simulation - given in 1/10 minutes.

Due to the nature of the GPSS language input changes must be made directly in the main body of the program.

4.3 Model Calibration

The MICRO model is not calibrated in the way that many other models are; rather, a validation process is used to ensure that any assumptions which are made do not cause the model to produce unreasonable results. This procedure has already been done in order to validate the model logic, but it would also have to be done to check any input assumptions which the user may make. In either case the validation procedure would basically be a trial-and-error examination of the assumptions versus the results.

4.4 Model Process

Major steps in the MICRO model simulation are:

1. Input specifications identify the endpoint as a yard and dock type. Amounts of legal and illegal parking available, number of docks, number of men, size of yard, and walking distances are all specified.

2. The time of day (peak or off-peak) is specified.

3. Truck arrives at endpoint.

4. Truck type selected.

5. Shipment weight selected.

6. Number of pieces in shipment selected.

7. Weight per piece (average) calculated.

8. If facility is available (i.e. dock), truck enters.

*9. If docks full, truck departs or enters queue for dock, or looks for on-street parking.

*10. If truck looks for on-street parking, it parks legally or illegally, or departs.

*11. Once truck is parked or in dock, driver goes to building, requests men/equipment (if required), goes to find agent, waits for agent, processes papers, waits for shipment preparation (if required) and returns to truck.

*12. Loading and/or unloading takes place in appropriate time spot during 11 above.

*13. Truck departs.

14. If truck was parked illegally on street, third party (passenger car) delay time is calculated.

These steps have been described for only one truck. However, in the model many trucks are each going through their operations simultaneously.

The model stops running after the appropriate number of hours (depending on peak or off-peak) have been simulated. At that point the outputs are produced.

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*Uses input distributions or equations in decision process

4.5 Model Output

The folloing outputs are produced by the MICRO model:

1. Endpoint type and time period.

2. List of selected inputs.

3. Endpoint summary:

   Number of trucks that arrived.

   Number of trucks that stopped.

   Number of trucks that completed operations during the simulation.

   Average total time for those trucks that completed operations.

   Number of trucks that parked on the street.

   Percent that parked illegally.

   Number of trucks that entered the facility.

4. Common activities:

   Average time looking for an agent.

   Average time waiting for signature.

   Number of pickups, average loading time and average pickup weight.

5. Dock activity:

   Average total time spent in the dock.

   Average time in queue for dock.

   Maximum length of dock queue.

   Average time to manoeuver.

   Average time waiting for men and equipment.

6. Non-Dock activities:

   Average time spent walking.

   Total hours of passenger vehicle delay.

All of the values output as averages are also available in histogram form.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

The MICRO model is written in the GPSS simulation language, and therefore it can only be run on IBM installations which have the capability to process GPSS programs. No precise estimates of the computer time or cost requirements were available, though one of the researchers involved in the development of the model felt that the requirements would be moderate (roughly thirty to fifty dollars per run).

5.2 Time and Staff Requirements

The MICRO model was developed and applied as part of an urban goods movement modelling package; therefore, the effort required to implement the MICRO model by itself could not be easily estimated. The data required by the model is not of the type which is generally available, and it would have to be collected specifically for an application.

Since changes to the model input must be made directly in the main body of the program due to the nature of the GPSS language, the time required to calibrate the model would depend heavily upon the user's familiarity with GPSS. Similarly, the effort required to use the model to investigate the effects of changes to the system would depend upon user familiarity, as well as the scope of the changes being made. The output of the MICRO model is straightforward and the interpretation of the results would not require substantial effort.

6. APPLICATIONS

The MICRO model was applied using data collected in the City of Calgary as part of an urban goods movement study done for the Urban Transportation Research Branch of Transport Canada.

7. BIBLIOGRAPHY

N.D. Lea and Associates, Urban Goods Movement Study, Phase I Report, prepared for Transport Canada, 1972

1. TITLE

Municipal Financial Impact Model

2. PRINCIPAL RESEARCHERS

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Mr. Kriss was with Peat, Marwick and Partners, Toronto, at the time the model was under development.

3. AVAILABILITY

The Municipal Financial Impact Model can be obtained upon receiving approval from the Commissioner of Finance of the City of Mississauga. Although a detailed user's manual is not available, there is sufficient user-oriented documentation for the model to be applied without extensive outside help.

4. MODEL DESCRIPTION

4.1 Summary Description

The Municipal Financial Impact Model is an evaluation model, created in 1974 as part of the Mississauga Urban Development and Transportation Study undertaken by the IBI Group and Peat, Marwick and Partners. It was developed to assess the financial implications of alternative growth scenarios in that municipality. The growth scenarios differed from one another in terms of population and employment growth rates, the relative timing of population and employment growth, average housing density, land use pattern, average household income, and employment mix.

The model was designed to be used both in the strategic urban development study and as an on-going planning tool by the local planning department to evaluate the financial impacts of:

- particular major proposals by developers
- changes in the level of particular municipal services
- anticipated changes in the level or terms of Provincial grants
- changes in the City's or Region's policies on the financing of capital expenditures
- changes in the economic environment, eg: interest rates.

The financial impact model is divided into two phases. The first phase involves the projection of annual values for the capital expenditures,

operating costs and operating revenues associated with each municipal service for the duration of the forecast period. The second phase translates the service cost and revenue projections into estimates of the consequent financial impact on the City. This is a process involving the financing of capital and operating costs on a year-by-year basis. It requires the consideration of a wide range of factors in addition to the service cost and revenue projections themselves. These other factors include the growth of municipal assessment, a variety of municipal and Provincial Government policies, and considerable historical information such as on existing debt. The computer program carrys out this process and thus enables many alternatives to be studied.

The planning departments of most municipalities should be able to apply the model in-house given staff with some background in computer programming and finance. Since there is no detailed user's manual available, limited outside help may be required initially.

4.2 Inputs Required

The following base year data is required for the application of the Municipal Financial Impact Model:

- Existing Population
- Existing Residential Assessment
- Existing Commercial/Industrial Assessment
- Opening Balance in Developers' Reserve
- Opening Balance of Bank Loans
- Starting Profit Surplus, Opening Debt, and Principal and Interest Payments on Opening Debt Service. Example services include:
  - Eduction
  - General Administration
  - Public Transit
  - Roads
  - Storm Sewers
  - Sanitary Sewers
  - Refuse Collection and Disposal
  - Police
  - Fire
  - Social Services
  - Health
  - Parks and Recreation
  - Culture

Estimates of the future values of a number of characteristics are also required for the application of the model. These include:

Population -	the total population of the municipality for each year of the period being studied;
Households -	the total number of households in the municipality for each year;
Household - Income	average income per household in real dollars for each year;
Residential-Assessment	considered to vary with population growth and with housing density
Commercial/-Industrial Assessment	considered to vary with the number of employees and their type

The policy assumptions which must be made for the application of the model fall into the following categories:

- grant structure
- debentures and other debt
- developer levies and reserves
- mill rate ratios

The model permits the user to select the types of senior government grants that will be assumed to apply during the first period. Grants may be specific to a particular service or they may be general, that is, not service related.

Service - specific grants may include:

- grants as a proportion of operating loss
- grants as a proportion of all annual costs
- grant as a proportion of operating cost
- per capita grants
- grants as a proportion of capital expenditures

General grants may include:

- per capita grants
- fixed dollar amounts
- grants as a proportion of net cost of general municipal services

Under the category debentures and other debt, the model permits the user to specify which capital expenditures would be financed through the issuance of long-term debt and the terms to be used for simulated debentures. For the developer levies and reserves category, the user may specify a levy rate and a policy concerning the use of developer reserves. The ratio of future residential to commercial/industrial mill rates must be provided to the model both for general municipal services and education.

4.3 Model Calibration

The Municipal Financial Impact Model does not have a calibration phase; however the model must be validated to ensure that the assumptions made for some of the input variables will yield the correct results. This is done by applying the model to historical data and comparing the resulting output to actual values.

4.4 Model Process

The main function of the Municipal Financial Impact Model is to do a 'pro forma' calculation of future mill rates, debt levels, and other financial implications based on certain assumptions about future developments, capital and operating expenditures, senior government municipal grants, and debt financing. In the first stage of the application of the model the necessary assumptions must be made manually. The process used by the computer program to perform the second stage of the model is a step-by-step calculation of the intermediate and final output results from the input data. The main elements of this process are outlined briefly below.

For each year being modelled the program takes the capital expenditures associated with each service and deducts from them any applicable grants. The remainder is then financed according to rules defined by the input variables. If the municipal debt ceiling has been reached, all capital expenditures are financed from current revenue. The program computes the debt interest and repayment schedules for any simulated debentures issued to finance capital expenditures.

The program then examines the operating revenues and costs for each service. User charges and service related grants are deducted from operating costs in accordance with rules defined by the user. The resultant amounts must be paid by the municipality to cover each service's operating costs for the year being modelled. The program adds to these amounts the debt repayment requirements and any capital expenditures which were not financed through debentures or developer levies. These sums are used to compute the net costs of education and of all other municipal services. Grants in lieu of taxes, non service-related grants and other tax revenue (such as licence fees) are deducted from these costs to obtain the net property tax requirements.

The program then computes the mill rates required to cover the net property tax given residential and commercial/industrial assessments and the desired ratio between the millrates of the two categories.

4.5 Model Output

The computer program produces six separate reports which detail the forecast financial impact. The contents of these reports are summarized below:

1. Costs of Services shows, for each service and for each forecast year, the operating and capital costs, and the service-specific revenue, grants and funding.

2. Summary of Service Costs shows the same information as in the previous report, but split into only two service categories: Education, and the total of all General Municipal Services.

3. Debt Statistics shows, for Education and for the total of all General Municipal Services, the debt outstanding at the beginning and at the end of each forecast year and also the new debt issued and the principal retired during each year.

4. Statement of Capital Funding shows the amount to be financed each year and the ways this financing was achieved. This same report includes a Statement of Developer's Reserves showing, for each forecast year, the opening and closing balances, and also the revenue to and capital appropriation from the reserves.

5. Statement of Municipal Expenditures is divided into two parts. The top part shows separately for Education and for the total of all General Municipal Services how the Total Gross Service Costs were reduced by user charges, allocations from surplus (if any), grants, and miscellaneous taxes to yield the revenue required from property and business taxes. This revenue requirement is then translated into the mill rate levies. The bottom part of the report presents overall totals of the mill rates, taxable assessments, and total taxation.

6. Summary Statistics is a listing of selected scenario statistics and indicators.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

The Municipal Financial Impact Model computer program is written in standard Fortran and could be run on most computer installations. The core storage requirements are moderate and the CPU time for a typical run is relatively short. Average commercial costs per run are in the order of a few dollars.

5.2 Time and Staff Requirements

The effort required to collect the data required by the model can range from moderate to substantial. In order to apply the model, estimates of both future capital expenditures and operating costs are required for each service provided by the municipality. The time and staff effort needed for

this task depends upon what information is available from municipal records and from previous planning studies.

After the required data have been collected and the input parameters have been determined, the time required for model validation would be roughly two weeks. The initial forecast run would take a day, while subsequent runs could be performed in even less time. Outside help, if needed at all, should not be required during these latter phases of model application.

The model output is structured so that the evaluation of the results should be relatively straightforward. The summary statistics which are produced allow for easy comparison between alternatives.

6. APPLICATIONS

The Municipal Financial Impact Model was applied in Mississauga in 1974 in conjunction with an urban development study to evaluate the future financial implications of different urban development policies.

7. BIBLIOGRAPHY

"Mississauga Urban Development and Transportation Study, Volume 4, Finance", a report prepared by the IBI Group for the City of Mississauga, March 1975.

1. TITLE

MULTI-OBJECTIVE DYNAMIC PROGRAM

2. PRINCIPAL RESEARCHERS

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(Research financed by a grant from TDA)

3. AVAILABILITY

The programmed model has been generalized to suit most multi-objective evaluation procedures and is presently available for use. Program documentation and a user's manual are available while the publications listed in Section 7, Bibliography, provide examples of typical problems as well as inputs and outputs. The computer program is accessible only at the University of Calgary where it can be used at cost.

4. MODEL DESCRIPTION

4.1 Summary Description

The model provides an evaluative procedure with multi-objectives for project management. The objective of this program is to select a proposal consisting of various project components, which maximizes the overall benefits given budget constraints and a set of alternatives for each project component. It evaluates the proposals according to their economic viability and then reranks them according to their effectiveness in satisfying the selected objectives. A two-dimensional, multi-stage dynamic programming formulation is used to optimize the objective function. The program has been used for the optimal selection of large-scale project components associated with, for example, airports, urban transportation systems, etc.

The dynamic programming approach develops a formulation that expresses the contribution to the total objective function of the results of a policy at one stage (project) of the problem. This formulation is then used to determine the optimal policy for all possible alternatives of the system for the first stage of the problem. The results of this stage are then included in the next stage of the formulation. This recursive procedure is applied at

each stage until the last is reached, at which point the optimal policy is determined.

In order to successfully utilize this program a reasonably high degree of familiarity with dynamic programming as well as Fortran error diagnostics is required. The inputs to the model will require considerable knowledge and expertise in the operational aspects of the project. Presently, there are no modifications being made nor are any contemplated unless any problems are identified through future utilization.

4.2 Inputs Required

The program requires four basic inputs:

1. The relative weights (percentages) of the objectives as defined by the various interest groups involved in the project.

2. Implementation policies for the project relating to expenditures over time.

3. Budget constraint.

4. Alternatives for the various components and their associated costs expressed as a percentage of the total budget.

Overall the input requirements are relatively small, however, the performance of each alternative in terms of the objectives, although somewhat qualitative, can require considerable knowledge and research. The existing publicized applications have been principally concerned with the development of the methodology, but considerable work remains in developing appropriate weighting systems and measures of qualitative aspects. Past uses of this model have employed consessus building of the various groups involved in the project.

4.3 Model Process

The process is based on a two-dimensional multi-stage multi-objective dynamic programming approach. The original research in this field was conducted by Bellman who developed this mathematical optimization technique for making a series of interrelated decisions. Dynamic programming starts with a small portion of the problem and finds the optimal solution for this smaller problem. It then gradually enlarges the problem, finding the current optimal solution from the previous one, until the problem is solved in its entirety (see Exhibits 1 and 2). In contrast to other mathematical programming techniques, there is no standard mathematical formulation, rather, dynamic programming is a general strategy for optimization. Consequently, the particular equations used must be developed to fit each individual problem.

EXHIBIT 1

DISCRETE DYNAMIC PROGRAMMING LOGIC DIAGRAM

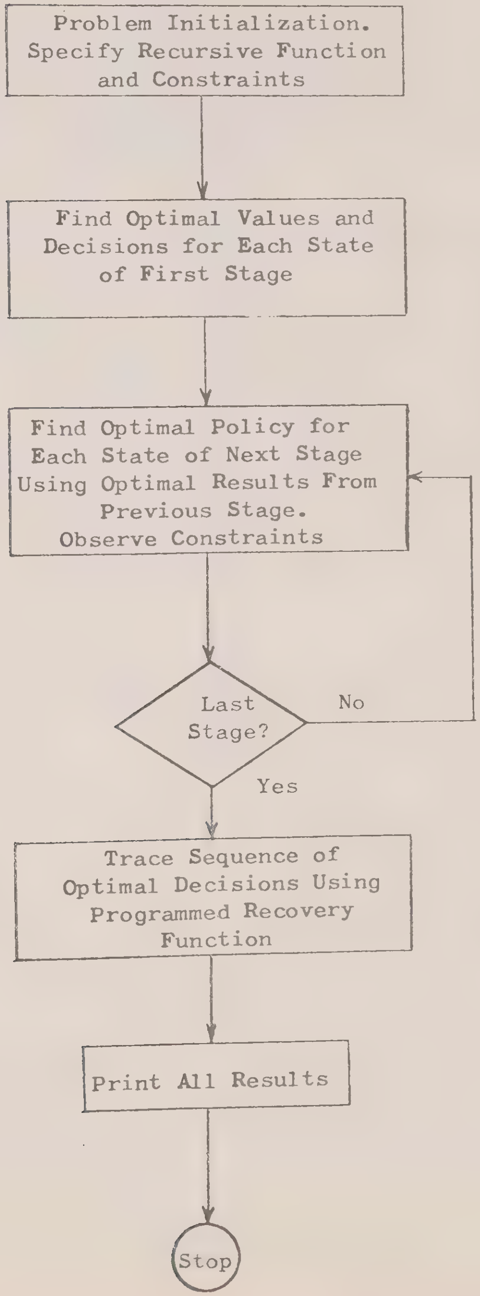
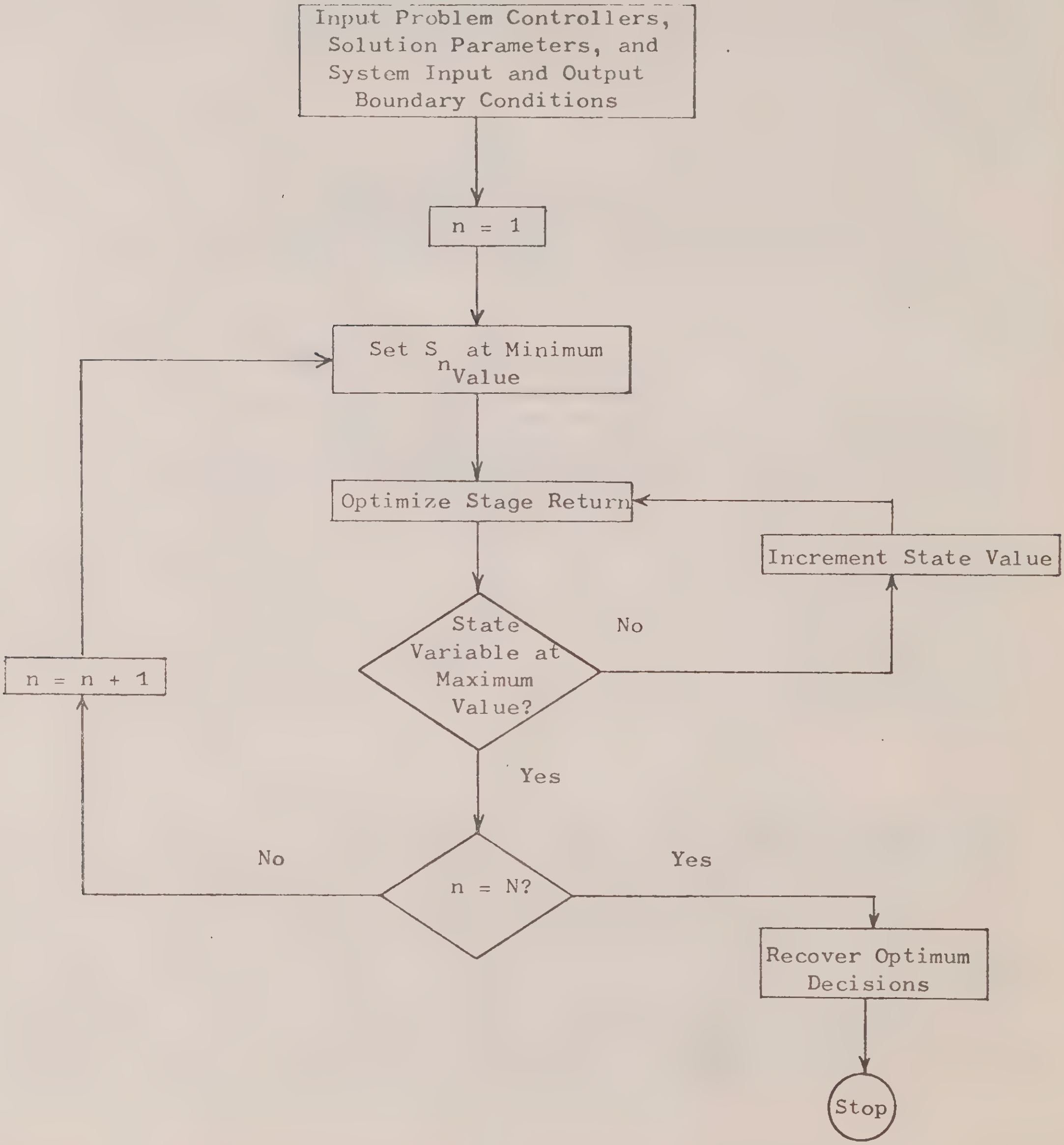


EXHIBIT 2

CONTINUOUS DYNAMIC PROGRAMMING
LOGIC DIAGRAM



The dynamic programming approach casts a problem into the following structure:

(i) The decision variables with their associated constraints are grouped according to stages, and the stages are considered sequentially.

(ii) The only information about previous stages relevant to selecting optimal values for the current decision variables is summarized by a so-called state variable, which may be n-dimensional.

(iii) The current decision, given the present state of the system, has a forecastable influence on the state at the next stage.

(iv) The optimality of the current decision is judged in terms of its forecasted economic impact on the present stage and on all subsequent stages.

Dynamic programming is essentially recursive optimization. The typical formulation for a continuous decision variable is:

$$f_i(x_1, x_2) = \max \; g_i(x_{i1}, x_{i2}) + f_{i-1}(x_1 - x_{i1}, x_2 - x_{i2})$$

$$0 \leq x_{i1} \leq x_1$$

$$0 \leq x_{i2} \leq x_2$$

for $\quad i = 1, 2, \ldots N$

$$f_i(x_1, x_2) = 0 \quad \text{for } i = 0$$

$$0 \leq x_1 \leq X_1$$

$$0 \leq x_2 \leq X_2$$

where

$f_i(x_1, x_2)$ = the optimal utility of the system with i projects with budget x_1 and x_2 for respective periods

X_1, X_2 = budget limitations for the first and second periods, respectively

x_{i1}, x_{i2} = resource allocation to Project i in respective periods.

$g_i(x_{i1}, x_{i2})$ = utility function due to investing x_{i1}, x_{i2} units in project i. This function is discrete and defined at small number of points.

For computation of dynamic programming problems, the optimal utility function $f_i(x_1, x_2)$, the values of x_1 and x_2 and the amount of allocation to the current project are determined at all stages to enable tracing back optimal allocation policies. The algorithm for a one-dimensional D.P. is described below and the basic procedure remains the same for two dimensional problems.

The optimal cumulative return function at stage i is found from the utility function of Project i and the optimal utility function for the other i-1 projects. Suppose that the utility function of Project i is defined at M values, x_{i1}, x_{i2} ... x_{iM} and the optimal utility function for the other i-1 projects is defined at L values, y_1, y_2 ... y_L. The steps are as follows:

Step 1: Calculate the sum, tr, for all combinations of investment levels of the utility function $g_i(x_i)$ and budget levels of the optimal utility function $f_{i-1}(y_h)$

$$tr = x_{ij} + y_h$$

where $x = 1, 2, \ldots, L \times M$

$j = 1, 2, \ldots, M$

$h = 1, 2, \ldots, L$

Check that every tr value is less than or equal to budget limitation X. If so, store tr, j, and h in x_k, J_k, and H_k respectively. Otherwise discard them.

Step 2: Arrange x_k in ascending order of magnitude, and rearrange values of J_k and H_k accordingly. The values of x_k are possible budget levels in the new optimal utility function $f_i(x)$.

Step 3: Set B = $-\infty$

Step 4: Set k = 1

Step 5: Set j = J_k and h = H_k

Step 6: Find values of $g_i(x_{ij})$ and $f_{i-1}(y_h)$ and compute $a = g_i(x_{ij}) + f_{i-1}(y_h)$.

Step 7: Compare a with B. If x > B, set B = a and store a as a value of $f_i(x_k)$ associated with x_k. Store x_{ij} in $x_i(x_k)$. (resources allocated to Project i corresponding to x_k). Otherwise discard.

Step 8: Set k = k + 1. Repeat steps 4 to 7 for the new x_k. Finally we obtain the new optimal utility function $f_i(x)$ and resource allocations to the ith project at this stage.

4.4 Model Output

The program prints out the utility function and optimal functions associated with each stage. Each proposal is printed out with its accompanying optimal investment policy. The benefits of each project component for the given set of objectives are also printed. Finally, the proposals are ranked in decreasing order of overall benefits. The paper entitled "Selection of Optimal Policies for Airport Projects" by the principal researchers provides a clear example of the final output as well as input structures.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

The program was developed on a CDC 6400 computer at the University of Calgary and is principally written in Fortran. However, several of the subroutines were written in COMPASS, a machine language, to implement a virtual memory system. Thus, the program is compatible only with CDC computers with reasonably large core space. Additional disk storage space is also required.

5.2 Staff and Time Requirements

The data required for the model are unique to each project and consequently the inputs are quite time consuming and costly to develop. (The amount of time spent in this stage will determine the relative accuracy of the results.) Because a user needs to be familiar with dynamic programming as well as the computer error messages generated by the program, most users will initially require help from outside experts. Thereafter, in-house staff, trained during the models initial use, could run the program. In light of the new computer being installed (a Honeywell machine) at the University of Calgary, considerable work will have to be done to produce a compatible program. This will

include translating the COMPASS routeines to other assembly languages. Such a task could create a considerable delay and cost the first time the program is used.

The CPU time required for such problems varies with the number of components in the project and the number of alternatives associated with each:

Components	Alternatives	CPU Time
3	5	1 Min.
9	3	20 Min.

6. APPLICATIONS

Until now, the program has been used principally in a research or illustrative capacity, and has not been used in any practical situations. The bibliography provides a list of research papers where uses of the program are discussed.

7. BIBLIOGRAPHY

Sargious, M.A., and J.J. Salinas, 1976, Selection of Optimal Policies for Airport Projects, Canadian Journal of Civil Engineering, No. 3, Vol. 3, pp. 428-436.

__________________________, Selection of Urban Transit Systems in Cities With Less Than 500,000 Population, The Logistics and Transportation Review, No. 2, Vol. 11, pp. 129-143.

Sargious, M.A., and H. Olson, 1978, Systems Analysis of Airport Parking Facilities, Canadian Journal of Civil Engineering, No. 3, Vol. 5, pp. 129-402.

Kuester, J. L. and J. H. Mize, 1973, Optimization Techniques With Fortran, McGraw-Hill Book Co., Toronto.

Wagner, H. M., 1979, Principles of Management Science, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Bellman, R., 1957, Dynamic Programming, Princeton Unviersity Press, Princeton, New Jersey.

APPENDIX C

DESCRIPTIONS OF ESTABLISHED CANADIAN MODELS AND PACKAGES

DESCRIPTIONS OF ESTABLISHED
CANADIAN MODELS AND PACKAGES

TABLE OF CONTENTS

1. TITLE

Waterloo Land Use Transport Model.

2. PRINCIPAL RESEARCHER

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3. AVAILABILITY OF MODEL

The model and a program write-up are available from the principal researcher upon request. There is no charge for the computer program other than copying costs. Documentation on the model is not extensive, but probably sufficient for any user with some background in land use/transportation models. No modifications are required to the computer program for the application of this model.

4. MODEL DESCRIPTION

4.1 Summary Description

The Waterloo Land Use-Transport Model is a derivative of the Lowry model which allows activity allocations and transport flows to be estimated simultaneously. The model was developed in 1973, and has been used since then in a number of applications.

The basic function of the model is to estimate the demands for household opportunities by income group at each workplace location (traffic zone) and then to allocate the demands to compatible housing opportunities. The model has the capability of allocating household demands to housing opportunities in such a way that the demand allocated to any one urban place (or traffic zone) does not exceed the opportunities available at that urban place. The model computer program calculates as well the work to home origin and destination matrix for each group.

The model initially converts the employment opportunities by employment sector for each zone into employment opportunities by income group using an income group-employment sector type probability matrix. This matrix shows the probabilities of employees in each income group being represented in each sector. These employment opportunities by income group are then converted into household demands by income group at each zone which must find residential locations throughout the region.

The model also calculates the spatial distribution of household opportunities by income group. The expected household opportunities by broad density class are converted into a supply of housing opportunities for each income group at each urban place. This conversion takes place through the use of an income group-household density class probability matrix. This matrix shows the probabilities of employees in each income group living in housing within each density class.

The demands for household opportunities by income group at each workplace location are then allocated to compatible housing opportunities using a constrained residential sub-model of a Lowry-type land use model. The structure of this land use model is described briefly in the section on model process.

The model is relatively straightforward and could be used by most transportation planning departments given some background in land use models and limited computer programming experience. Model development was completed in 1973 and no major changes have been made since then.

4.2 Inputs Required

When the model is used to forecast household allocations and transport flows, the following inputs are required:

- Employment - employment by category for each zone
  - these employment figures are converted to household demands by income group using the employment associated matrices
- Employment matrices
  - occupation type (professional, clerical, labour) - employment category (manufacturing, service, retail) probability matrix
  - employee income group (low, medium, high) - occupation type probability matrix
  - employees by household income group - employees by income group probability matrix
  - labour participation rate by household income group.
- Population - total population by zone.
- Housing densities
  - percentages of each type of housing density by zone
  - persons per household for each density type
  - the number of housing opportunities available in each zone is determined by the population and housing density percentages

- Housing Matrix
  - household income group - housing density type probability matrix
  - this matrix is combined with the household opportunities by density for each zone to obtain the household supply by income group for each zone
- Transport network
  - a network representing the major road and transit links in the urban area
  - skim trees can be created from this network
- Travel time factor parameters
  - by trip type, mode and income group
- Trip generation rates
  - generation rates by trip purpose

4.3 Model Calibration

Historical data can be used to estimate the employment and housing probability matrices. This process is not really calibration, but it must be performed before the model is used for forecasting.

The travel time factor parameters must be calibrated in the usual sense. The computer program can be run using existing data and various values of the travel time factor. The resulting trip length distributions would then be compared to the actual distribution and the most appropriate travel time factors would be identified.

4.4 Model Process

A flow diagram which shows the process used by the model computer program is given in Figure 1. The model process consists of two parts. The first part converts the input information into household demand and supply by income group. This part of the process has been described earlier. The second part of the process allocates the household demands in either a constrained or unconstrained manner and calculates the home based work trip tables at the same time.

The demand for households is allocated to residential opportunities by the following equation:

$$\ell^k_{ij} = e^k_i a^k [h^k_j \exp(-\alpha_i d^k_{ij}) / \sum_j h^k_j (-\alpha_i d^k_{ij})$$

where ℓ^k_{ij} = the number of households in zone j used by employees in zone i in income group k

e^k_i = the employment in zone i by income group k

a^k = the labour participation rate by income group k

h^k_j = the number of housing opportunities in zone j for income group k

α^k_i = a parameter which reflects the influence that travel time has on residential location

d^k_{ij} = the travel time by the mode used by income group k in searching for a household location

Home based trip interchanges by income group and transportation mode are then calculated using trip generation rates supplied by the user. These trip tables are aggregated and assigned to a given network using all-or-nothing assignment.

4.5 Model Outputs

A number of output options can be called for from the computer program. Some of the specific results which can be obtained include:

- Work to Home trip interchanges by income group and transportation mode
- Work to Home trip length frequency histograms by income group and transportation mode
- Home to Service trip interchanges by service type, income group and transportation mode
- Home to Service trip length frequency histograms by service type, income group and transportation mode
- Work to home trip assignment by transportation mode
- Home to service trip assignment by transportation mode

In addition most given information can be reproduced in the output of the computer program.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

The Waterloo Land Use Transport Model computer program is written in Fortran and can be run on IBM or CDC installations without any special hardware requirements. A typical cost for an application of this model to a sixty zone system is eighty dollars.

5.2 Time and Staff Requirements

The model requires considerable data in order to develop the employment and housing probability matrices which were discussed earlier. Much of this data is available from Statistics Canada and other standard sources. The amount of manipulation required to put the data into suitable form depends upon the compatibility of the data available to the input requirements.

The model is calibrated in the same manner as a gravity model, and therefore no outside help should be required for this task. After the probability matrices have been estimated, model calibration should not take more than a week.

When the model is used to forecast future trip interchanges, considerable effort may be required in order to estimate the future development by category and by zone and the future population by zone in the region under study. The effort is dependent upon the availability of estimates of this nature either from the study team or from outside sources such as Statistics Canada. The model output is straightforward and initial interpretation should not require more than a day or two. A more detailed evaluation of the results of various alternative land use strategies could require a few man-weeks.

6. APPLICATIONS

The Waterloo Land Use Transport Model has been practically applied in the Central Ontario Lakeshore Urban Complex (COLUC) study in 1974 and as part of the North Pickering Project, also in 1974. The model has also been used in Waterloo and Hamilton in research oriented applications.

7. BIBLIOGRAPHY

Hutchinson, B.G., Lowry Model Analyses of the COLUC Region, COLUC Task Force, Toronto, Ontario 1974

Hutchinson, B.G., North Pickering Community Analyses (A Background Paper), North Pickering Project, April 1974, Revised, March 1975.

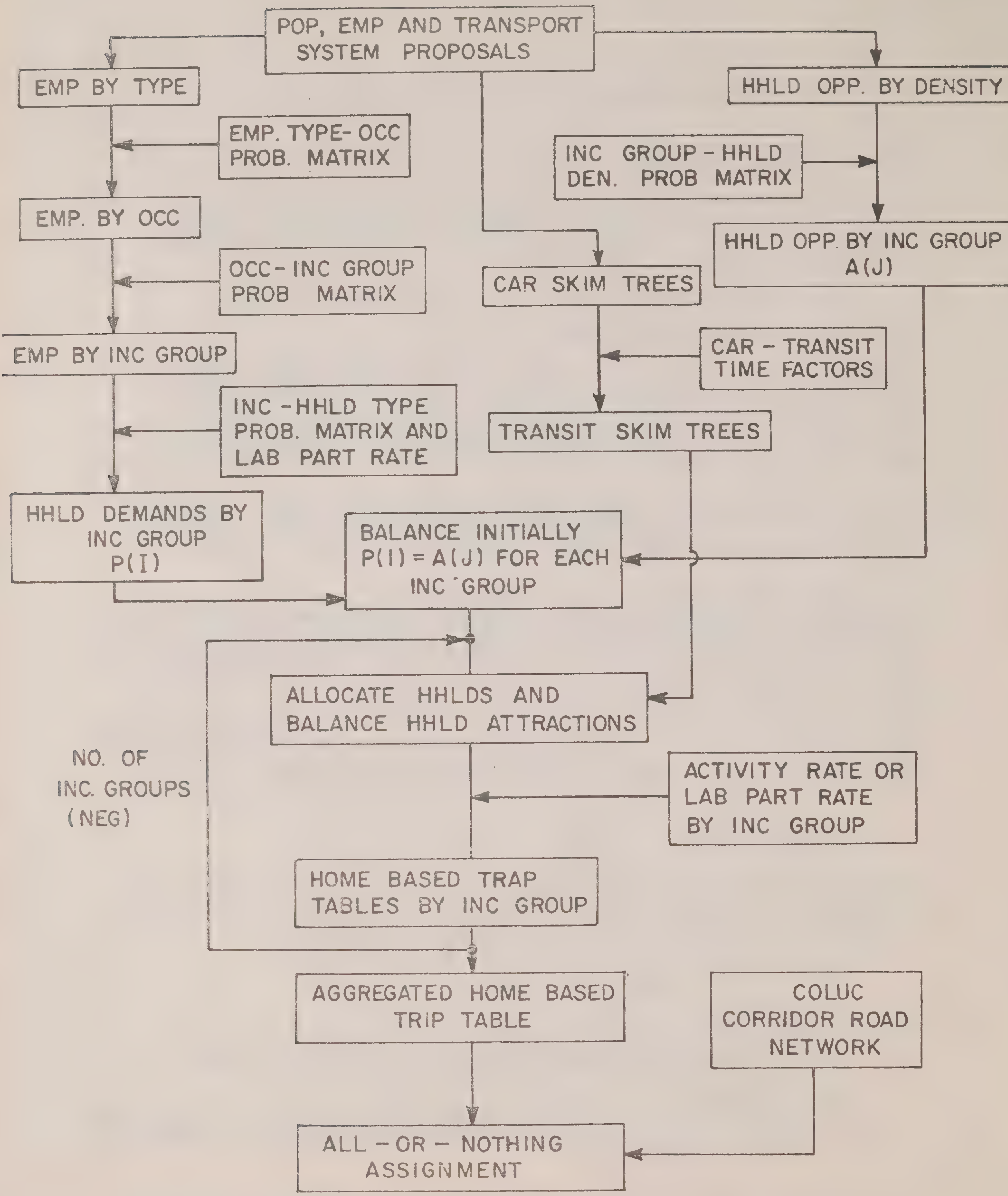

FIGURE 1 - COMPUTER PROGRAM FLOW DIAGRAM

1. TITLE

EMPIRIC

2. PRINCIPAL RESEARCHERS

Neal Irwin
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IBI Group
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3. AVAILABILITY

The EMPIRIC model can be supplied and calibrated by the IBI Group on a contract basis. After calibration, the model can be used 'in-house' without the involvement of the IBI Group. The EMPIRIC model was applied as part of the Toronto Area Airports Project for Transport Canada, and therefore, the EMPIRIC computer programs and limited documentation may also be available for that source.

4. MODEL DESCRIPTION

4.1 Summary Description

The "EMPIRIC" Model is one of a family of regional planning models - referred to generically as "activity allocation" models - which are designed to allocate projected regional population, employment, and land-use growth among a set of smaller sub-regions or districts.

The model was originally developed in 1962-63 by Messrs. Irwin, Hill, Brand et al at Traffic Research Corporation (TRC) to test alternative development plans to the Eastern Massachusetts Region.

The model is designed to perform three specific functions:

- To estimate the impact of alternative public and private planning policy decisions on the future distribution of regional activity.
- To generate small-area forecasts of population, employment and land-use, based on exogenously specified regional totals and exogenously specified planning policies.
- To serve as a mechanism for analyzing, inter-relating and co-ordinating future public policy decisions.

The model consists mathematically of a set of simultaneous linear equations, relating changes over time in the distribution of regional population and employment to their original distribution in some base year, their region-wide growth over a series of specified fore cast periods, and the predicted effects of selected, exogenously specified planning policies.

The main model is calibrated using activity and policy data developed for two points in time, usually five or ten years apart. "Activities" are defined as small area population totals and employment counts broken down by aggregated SIC (Standard Industrial Classification) code. Planning policy and investment decisions are expressed as changes over time in such terms as airport activity, regional highway and transit accessibilities, public utilities (e.g. water and/or sewer) and land use and zoning controls.

The calibration process estimates values for the coefficients of the simultaneous linear equations which interrelate the changes in activity distribution to both policy variables and other variables which are exogenously specified.

Forecasts of the future distribution of these activities are generated by specifying regional control totals for each activity at some forecast year together with a set of future development and planning policies.

The application of the EMPIRIC model should be within the scope of the planning departments of most Canadian cities. The prospective user should have a good knowledge of land-use models and some background in statistics.

The model is fully operational and has had numerous applications. There have been no recent changes in the computer programs of the EMPIRIC model.

4.2 Inputs Required

The input requirements of the Empiric Growth Allocation model depend upon the application. For example, in the application of the model undertaken as part of the Toronto Area Airports Project, historical data was required on the following variables on a zonal basis.

Dependent Variables

Change in Population (POP)
Change in Manufacturing and Wholesale Employment (M&W)
Change in Retail, Service and Other Employment (RSO)

Independent Variables

Population
Manufacturing and Wholesale Employment
Retail, Service and Other Employment
Dwelling Units
Road Accessibility to Population
Road Accessibility to M & W Employment
Road Accessibility to RSO Employment
Water Capacity (M.G.D.)
Pollution Control Capacity (M.G.D.)
Serviced Population (Water)

cont...

Independent Variables con't...

Serviced Population (Pollution Control)
Threshold Services (min. of Water, Pollution)
Airport Access (Road) Weighted by Airport Role
Road Access to Downtown
Transit Access to Downtown
Population Density
Residential Density
Gross-Residential Acres
Vacant Acres
Industrial Acres
Gross Acres
Residential Acres

When the model is used for forecasting after it has been calibrated, estimates the future values of the independent variables are required. Those variables which would be defined exogenously can be classified as environmental assumptions, while those variables which the user can control would be classified as policy variables.

In the Toronto

- Airport Roles - evaluated by the airport access variable
- Ground Transportation Concepts - evaluated by the road and transit access to downtown variables, the airport access variable and the various accessibility to population and employment variables.
- Zoning Alternatives - represented by the residential acres variable.
- Servicing Priorities - tested using the water or pollution control capacity variables

The Empiric model also used a number of parameters. These are the coefficients of the simultaneous linear equations which define the dependent variables as functions of the independent variables.

4.3 Model Calibration

The calibration phase of the EMPIRIC model uses a number of separate program blocks which perform three basic functions - data analysis, parameter estimation, and reliability testing - as shown in Figure 1. The program blocks are described below:

"GRAPH" is a simple graphical output routine, providing for the graphical comparison of any two variables contained within the basic data set, optionally stratified by ranges of a third variable.

"DACOR" is a simple, bi-variate correlation program. It is used to examine spatial and functional collinearities within the data set available for calibration, as an aid in variable formulation.

"FACTOR" is a basic factor analysis program used to identify spatial and functional collinearities in the calibration data set. It is used as a supplement to DACOR in variable formulation prior to calibration.

"REGFAC" is the basic module used in the estimation of model coefficients during the process of calibration. It consists of four subprograms, two of which are described below:

i. Ordinary Least Squares - a standard least squares regression package, used in the initial stages of calibration and in the construction of independent submodels operating on the output of the simultaneous equation model.

ii. Two-Staged Least Squares - a standard, simultaneous equation regression package, used to estimate the coefficients in the basic EMPIRIC model using the method of two-stage least squares.

The output of each of these programs is a set of coefficients, together with associated R , and t values for the calibrated model.

"RELIAB" is a reliability testing program, used to evaluate the efficiency of the calibrated model by comparing its output with observed data for each subregion. The output includes values of R^2, Root-Mean Square Error and Root-Mean-Square Error Ratio for each activity computed across all subregions.

4.4 Model Process

When the Empiric model is applied in a forecasting mode two separate program blocks are used. Both are briefly described below:

"FORCST" is the main forecasting program used to estimate the future regional distribtuion of activities. It accepts as input the calibrated model, together with estimated base-year and forecast-year policy data and environmental assumptions. As output, it generates estimated subregionals shares of regional activity, together with the equivalent projections of subregional activity levels. "FORCST" also contains an option which allows for the exogenous specification of major developments.

"MONITO" is a program used to monitor the projected sub-regional activity levels, to compare these with exogenously specified maximum - minimum levels, and to adjust the forecasts to account for any discrepancy between the two. Constant regional control totals are maintained by distributing any resulting activity surpluses or deficits among other sub-regions in proportion to their predicted changes in activity level.

4.5 Model Output

The basic outputs of the EMPIRIC model are estimates of the future values of the dependent variables on a zonal basis. In the Toronto example previously discussed, the dependent variables were the zonal changes in population, manufacturing and wholesale employment, and retail, service and other employment.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

The EMPIRIC model package is programmed to operate on the IBM 360 series of computers running under the full operating system (OS/360). The programs can be successfully operated on any model that has adequate hardware, but practical considerations limit this to a Model 40 or above. The programs are also compatible with IBM370 series machines.

All EMPIRIC programs feature dynamic core allocation and thus are self-adjusting in terms of core requirements in accordance with the particular problem being executed. Each of the programs can perform its basic functions and run in less than 100K. However, program efficiency in some cases is improved by utilizing a larger region size which permits more efficient blocking of input data, fuller utilization of the multiple input capabilities of some of the programs, and/or increased computational efficiency.

EMPIRIC is most efficiently used by employing one or more disk packs. The programs can be stored in a load module library at a considerable savings in time and expense over card input with recompilation and link editing each time the programs are to be run. Data sets are also conveniently stored on disk packs although magnetic tapes may also be utilized. EMPIRIC requires only the standard system output devices of card reader, line printer, and card punch, but has also been used successfully with a variety of remote input output devices.

5.2 Time & Staff Requirements

The data requirements of the EMPIRIC model are dependent upon the nature and scope of the application. Therefore, it is difficult to estimate the typical effort required to collect data. Generally the type of information used by the model would be readily available from sources such as Statistics Canada.

Most of the staff time needed to apply the EMPIRIC model would be associated with model calibration. Typically, several man-months would be required for this phase. Running the model after calibration would require less effort, most of which would be used to estimate the future values of the independent variables.

The evaluation of the results would require a comparatively modest effort which would be centered on the comparison of the outputs of different alternatives.

6. APPLICATIONS

The EMPIRIC package was developed originally for the Boston, Massachusetts region, under the auspices of the Eastern Massachusetts Regional Planning Project in the early 1960's. It has since been applied successfully in Southern Massachusetts; Washington, D.C.; Winnipeg, Manitoba; Minneapolis - St. Paul, Minnesota; Seattle, Washington; Denver, Colorado; Toronto, Ontario; and northwestern England.

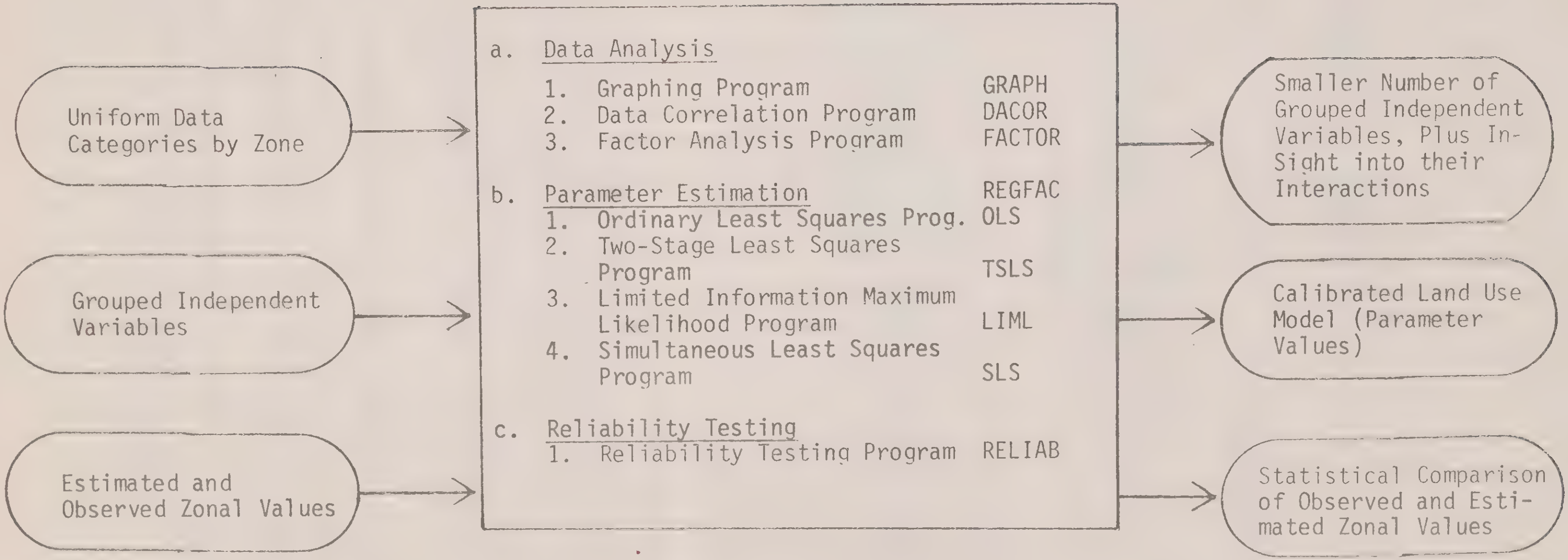
7. BIBLIOGRAPHY

Irwin, N.A. et al, "Understanding the Urban Process: The Empiric Growth Allocation Model", A paper presented at the Canadian Operational Research Society National Conference", May 1973.

Kates, Peat, Marwick & Co., "Developing a Growth Allocation Procedure for Forecasting Land Use in a Metropolitan Area", A report prepared for The Canadian Council on Urban and Regional Research and The Metropolitan Corporation of Greater Winnipeg. December 1969.

FIGURE 1

MODEL CALIBRATION



1. TITLE

ACRES' STAP 2: Simplified Travel Analysis Procedure, Version 2

2. PRINCIPAL RESEARCHER

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3. AVAILABILITY

The STAP 2 programs are supplied and calibrated by Acres Consulting Services Ltd. on a contract basis for regular commercial rates. After the initial implementation of the models, the programs may be used 'in-house' without the involvement of Acres. Published documentation on STAP 2 is limited, although there are a number of unpublished working papers which were prepared by the principal researcher.

4. MODEL DESCRIPTION

4.1 Summary Description

Acres STAP 2 includes the four standard steps which most travel simulation models consist of: trip generation, trip distribution, modal split and trip assignment. STAP 2 was designed to simulate the impacts of medium and long range alternative regional land use/transportation scenarios and policy options at a relatively coarse scale. The model was developed by Acres Consulting Services Limited in 1976-77 and is based on the simulation procedure used in the Metropolitan Toronto Transportation Plan Review (MTTPR).

The four steps of the STAP 2 model operate in sequence to:

1) Estimate the total amount of trip making by zone;
2) Distribute trips from each origin zone among potential destination zones;
3) Divide trips between the auto and transit modes; and
4) Assign trips to the road and/or transit network.

The trip generation component is performed manually while trip distribution, modal split and assignment are undertaken using a remote APL computer terminal which operates on a time sharing basis.

STAP 2 simulates 24 hour home-based work travel in order to estimate the average daily (ADT) and peak hour travel implication of land use and transportation system alternatives.

In STAP 2 trip generation is defined as the number of home-based work trips produced in each zone of residence and/or attracted to each zone of employment in a 24 hour weekday period. The number of trips are calculated manually as a function of the resident (active) labour force and employment found in each zone and zonal trip generation rates (trips per day per member of the labour force and per employee).

The trip distribution component of the model uses a modified gravity formula which takes into consideration labour force employment compatibility. The compatibility factor in the formula is an interchange specific number indicating the relevance of jobs at zone j to labour force resident at zone i. Average compatibility is neutral (or 1) with values above 1 indicating greater than average inter-zoned compatibility and values below 1 indicating below average compatibility.

Both the modal split and assignment components are standard. The former uses diversion curves while the latter assigns trips between each zone pair to the least cost path(minimum travel time) with no consideration of the effects of facility loading on travel times (all or nothing assignment).

The STAP 2 computer programs are written in APL language, and are interactive ; input data can be entered through a key board on a remote terminal. The model, once calibrated is relatively easy to run, and anyone with some background in transportation models should be able to use it in strategic planning applications.

Initial development of the model is complete. However the principal researcher would adapt the model as required for a specific application.

4.2 Inputs Required

The following historical data are required for the calibration of the STAP 2 model:

- road network characteristics, link travel times and flow directions;
- screenline traffic counts
- vehicle occupancy, peak hour travel at screenlines, ratio of work trips to trips for other purposes;
- employed labour force by category for each traffic zone;

- employment by category for each traffic zone
- place-of-work by place-of-residence origin-destination table.

The last two are obtained from 1971 Statistics Canada Census 'Place-of-Work' data.

In addition to these data, the trip generation rates must be estimated for use both in model calibration and application. Also when the model is applied to the analysis of future land use/transportation alternatives estimates must be made of the employed labour force and the employment by category for each traffic zone.

The major policy variables of the model are the characteristics of the future road network. Other policy variables might include the labour force and employment in zones undergoing development in the future.

Finally there are a number of parameters and functions which must be calibrated by the model user:

- form of the impedance function and value of the associated parameter;
- general functional relationship between the employment compatibility index and the compatibility factor;
- other parameters such as the average week-day travel (AWDT) factor and the peak-hour (PH) factor.

4.3 Model Calibration

The calibration of the STAP 2 model primarily involves the trip distribution component. Initially the model is run using historical data and one of four different forms of the impedance function with various parameter values. The functional form and parameter value which yield the best fit are identified. Implicit compatibility factors are then derived to account for any variation between observed behavior and that simulated on the basis of the best fitting impedance function. A statistical relationship between these 'implicit' factors and compatibility indices, which are derived independently using census data, is obtained. The compatibility factors based on this relationship are calculated and inputed to the trip distribution component.

The values of the other parameters and factors used in STAP 2 are estimated from observed traffic data.

4.4 Model Process

The process that STAP 2 utilizes to forecast 24-hour home based work trips after calibration is relatively straightforward.

The model has four components; or sub-models: Network, Trip Generation, Trip Distribution, and Assignment. These operate in sequence to:

1) Calculate the minimum inter-zonal travel times and the shortest routes between each pair of zones on the user specified road network.

2) Estimate the total amount of trip-making to and from each traffic zone. This would be a function of the trip generation rates and the employed labour force and the employment in each traffic zone.

3) Distribute trips (or members of the labour force) from zones of residence to zones of employment.

In STAP 2 trip distribtuion is performed by applying the following equation to the production and attraction values established in the trip generation phase. An iterative balancing equation is also applied so that the computed attractions are equal to the expected attractions.

$$Tij = Pi \frac{Aj \quad Cij \quad Fij}{\sum_{j=1}^{n} Aj \quad Cij \quad Fij}$$

Where:

Tij = Trip interchange between zones i and j.

Pi = Trips produced at i.

Aj = Trips attracted to j.

Cij = The compatibility factor, an interchange-specific number indicating the relevance of jobs at zone j to labour force resident at zone i.

Fij = The impedance factor, some function of travel time between zones i an j, such as

$$\frac{1}{TTij^{n}} \quad \text{or} \quad e^{-nTTij}$$

where TTij = travel time from zone i to zone j

4) Assign trips (or members of the labour force) to the shortest route available, on the road network between their origin (home) and destination (work place).

4.5 Model Output

The primary outputs of the STAP 2 model are inter-zonal home based work-trip interchanges on a 24 hour basis, and traffic flows on the road network. Peak-

hour and average week day traffic flows can also be obtained by using the appropriate factors.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

The Acres STAP 2 package consists of a set of computer programs written in APL, a computer programming language designed for use with interactive time-sharing terminals. Therefore, the programs would generally be applied through a remote computer terminal and the user would not require a computer installation of his own.

Computer time and cost requirements depend upon the complexity of the system being modelled. In the Haldimand-Norfolk application, the system consisted of roughly 40 traffic zones. A single run after the model was calibrated cost from $20 to $50 depending on whether or not the road network was altered from the initial run.

5.2 Time and Staff Requirements

Much of the data used in the model are available from Statistics Canada. Road network data and traffic information is required but not at a detailed level. The principal researcher feels that for a typical application several man-months would be required to assemble and manipulate the data needed for the initial calibration of the model. The calibration itself would require only a few days to a few weeks, depending upon the complexity of the system.

Policy runs of the model after calibration could be performed in a day. The evaluation of the results of these runs could take a week or more, depending upon how detailed a comparison was being made between alternatives.

6. APPLICATIONS

Acres STAP 2 was applied in the Regional Municipality of Haldimand-Norfold in Ontario as part of the preparation of a Regional Official Plan.

7. BIBLIOGRAPHY

Transportation Planning Study - Phase 1 Report, Policy Division, Regional Municipality of Haldimand-Norfold June, 1977.

Crowley, David F., Unpublished working papers, Acres Consulting Services Ltd., Toronto, Ontario.

1. TITLE

IBIMOD, a comprehensive traffic prediction model

2. PRINCIPAL RESEARCHER

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3. AVAILABILITY

IBIMOD was developed by staff of the IBI Group during the course of several projects. It has been improved and updated several times. A current version of the program is available from IBI Group. One version of the program, also known as PMPMOD, has been made available together with complete documentation to interested potential users by the Ontario Ministry of Transportation and Communications.

4. MODEL DESCRIPTION

4.1 Summary Description

IBIMOD is a comprehensive transportation planning model combining trip generation, distribution, modal split and assignment algorithms. The program itself consists of the following blocks or sub-routines:

1. Data entry and checking.
2. Trip generation.
3. Building of road network minimum time path trees.
4. Building of transit network minimum time path trees.
5. Gravity distribution model.
6. Modal split.
7. Assignment to transit network.
8. Assignment to road network.
9. Generation of summary statistics.

The model is usually run as a whole from beginning to end although it can be operated as far as the end of the fourth block and the built trees stored for subsequent use in other runs. In addition to these blocks it is possible to set a switch that will instruct the program to create a data file to allow capacity restrained assignments to the road network.

4.2 Inputs Required

The following are the main types of input required:

1. Land use characteristics by zone: these are used to predict total travel times from each zone. Such zonal land use characteristics can include:

   - population
   - employment in various sectors of the economy
   - population and employment densities
   - automobile ownership
   - income distribution
   - retail floor area
   - other land use activity variables thought relevant by the user.

   At the present time the program can handle up to 16 land use variables although this restriction could be easily relaxed.

2. Trip generation paramters: IBIMOD can examine up to 10 trip purposes simultaneously. Trips are generated, distributed and split by mode and by purpose before they are aggregated for the assignment blocks. For each trip purpose, a linear equation which specifies the number of trips generated and attracted to each zone on the basis of the various land use characteristics is specified. Additional trip ends can be added for special generators such as airports and other activities not taken into account by the equation.

3. Road network data: the road network is specified by a system of links and nodes. The nodes represent zonal centroids and various intersections on the network. Each link is coded with length, and speed or travel time. If the capacity restrained algorithm is to be used link capacities must also be specified. One additional item coded for each link is the link type. This can be used to facilitate modification of the speeds of all links of a particular type. In this way the characteristics of the network can be modified or additional facilities can be included in or deleted from the network without having to recode the links concerned individually. Therefore, to build the correct minimum time paths, a number of link type speed multipliers have to be specified as well; if the network is to be used as coded these will be coded as 1.0.

4. Transit network data: similarly the transit network is specified by a system of nodes and links. The nodes represent zonal centroids, access points from the zonal centroids to the physical transit system, transfer points, branch points on the transit network, etc. The links can represent the access links from centroids to the network, travel along the network, or transfers between routes. Each link is specified with a physical link and a travel time. Waiting time for vehicles is specified by increasing the corresponding access and transfer links to that route.

5. Distribution parameters: the distribution of trips for each purpose are estimated using a gravity model formulation that increases resistance to travel for longer travel times according to input parameters. The form of the distribution equations is:

$$T^k_{ij} = a^k_i \cdot b^k_j \cdot G^k_i \cdot A^k_j \cdot (W^k_c \cdot e^{(-B^k_c \cdot t^c_{ij})} + W^k_t \cdot e^{(-B^k_t \cdot t^t_{ij})})$$

Where:

Tij^k is the estimated number of trips between zone i and j for purpose k

G^k_i is the estimated number of trips generated by zone i for trip purpose k (generators) as computed earlier

A^k_j is the estimated number of trips attracted by zone j for trip purpose k (attractors) as computer earlier

a^k_i and b^k_j are row and column factors to ensure that the trips originating in zone i are equal to the generators in zone i and that the trips arriving in zone j are equal to the attractors in zone j for purpose k, i.e.:

$$\sum_j T^k_{ij} = G^k_i$$

and

$$\sum_i T^k_{ij} = A^k_j$$

W^k_c is the weight given to the travel times by auto mode for purpose k

B^k_c is the trip distribution parameter for the travel time by auto mode for this purpose

t^c_{ij} is the time from zone i to zone j by auto

t^t_{ij} is the time from zone i to j by public transit

W^k_t is the weight given to the transit times for purpose k

B^k_t is the trip distribution parameter for the transit times for purpose k

W^k_c, B^k_c, W^k_t, and B^k_t are established by the user during the calibration process.

The times used, t^c_{ij} and t^t_{ij} are from the shortest paths produced by the tree building algorithm. Internal trips within each zone (intra-zonals) are calculated at the same time using intra-zonal times by road and transit provided by the user.

The user must specify the weight assigned to the automobile and transit travel times in performing the distribution (W^k_c and W^k_t) as well as the trip distribution parameter used for the road and transit times respectively.

The distribution process is iterative and it ends when the average difference between zonal attractions as computed from the attraction equations and the distributed trip ends is less than a specified tolerance or when a specified maximum number of iterations has been performed. The user must specify both the tolerance and the maximum number of iterations for each trip purpose.

6. Modal split parameters: the first step in this stage is the modification of trip matrices, by purpose, to obtain the return portion of trips. For example, the model as calibrated normally distributes 24-hour home-based-work trips from the home origin to the work destination. The transposed matrix can be factored by 0.50 to obtain work-to-home trips, and can then be multiplied by a peak hour factor to obtain p.m. peak work-to-home trips. Other factors are used to obtain peak hour trips for all trip purposes.

   Next, any walking trips are subtracted from the trip matrix as follows:

$$T^{k1}_{ij} = T^k_{ij} \cdot (1-w^k\ (t^c_{ij}))$$

   Where:

   T^{k1}_{ij} is the total number of trips from zone i to zone j by auto or transit (excluding walk trips)

   T^k_{ij} is the total number of trips from zone i to zone j as determined in trip distribution

   w^k is the proportion of walk trips for purpose k and road time (t^c_{ij}), as input by the user.

   There are three methods available for splitting the remaining trips between the public transit and auto modes. Either the first or second method can be used independently by trip purpose; however, if the third method is chosen, it must be applied to all purposes.

The simplest of the three methods is the fixed modal split method. The transit trip matrix is obtained by multiplying the trip matrix (excluding walk trips) by a specified factor for each purpose. The car person trips are therefore the residual.

The second method uses input diversion curves in which the percent transit trips are related to relative car and transit travel times and to parking costs. Up to three sets of diversion curves can be specified, each of which can be assigned to any of the trip purposes. The equations are of the form:

$$T_{ij}^{kt} = T_{ij}^{k} \cdot m^{k}_{x,y} \left(t_{ij}^{t} - t_{ij}^{c}, p_{ij}\right)$$

Where:

T_{ij}^{k} is as defined earlier

T_{ij}^{kt} is a number of transit trips from zone i to zone j for purpose k

T_{ij}^{kc} is number of trips by auto from zone i to zone j for purpose k calculated by subtracting transit trips from total trips for each O/D pair

$t_{ij}^{t}-t_{ij}^{c}$ is travel time by transit less travel time by auto from zone i to zone j

p_{ij} is the parking cost per auto and is calculated as the higher of the costs in zone i and zone j

$m^{k}_{x,y}$ is the percent transit trips as determined from curves by interpolation for purpose k, x travel time difference and y parking cost.

The third method calculates modal split as a specific function of travel cost ratio between auto and transit, travel time difference, and optionally, transit frequency between zones. The function can be either linear or exponential in form, as below:

$$T_{ij}^{kt} = T_{ij}^{k} \cdot m^{k}_{t} \left(t_{ij}^{t} - t_{ij}^{c}\right) + m^{k}_{c} \left(cr_{ij}\right) + m^{k}_{f} \left(F_{ij}\right)$$

or

$$T_{ij}^{kt} = T_{ij}^{k} \cdot \exp \; m^{k}_{t} \left(t_{ij}^{t} - t_{ij}^{c}\right) + m^{k}_{c} \left(cr_{ij}\right) + m^{k}_{f} \left(F_{ij}\right)$$

Where:

T_{ij}^{kt}, T_{ij}^{k}, $t_{ij}^{t} - t_{ij}^{c}$ are as defined earlier

cr_{ij} is the cost ratio of auto travel (cost-per-mile plus parking) to transit travel (superzone-to-superzone fare) between zones i and j

F_{ij} is the transit service frequency between zones i and j

m_t^k, m_c^k, m_f^k are modal split parameters by purpose.

Upper and lower limits to the return values for modal split are specified to prevent meaningless results for possible extreme values of the independent variables.

7. Assignment: at the present time the assignment is on an all-or-nothing basis and therefore no assignment parameters are required. A select link feature is available which will, after specific links have been identified by the user, indicate which interchanges between pairs of zones used that specific link. Up to 10 such selected links can be chosen for each of the road and transit networks. If the capacity restraint program is to be used, the assignment algorithm will save the results of the all-or-nothing assignment to be the first interaction of the capacity restrained assignment.

4.3 Model Calibration

As with most other traffic prediction models, calibration can be a lengthy and complicated process. If complete information from a home interview survey is available, this can be done on a step-by-step procedure replicating trip generation, distribution, and a modal split for each purpose. However, in several applications all of this information has not been availalbe and calibrations have been performed against traffic counts summarized by screenline.

4.4 Model Process

Exhibit 1 shows the generalized flow chart of IBIMOD.

4.5 Model Output

The output of the IBIMOD program is standarized and relatively few options are available. In the past, the program has been modified to provide additional information to meet special requirements. The major outputs are as follows:

1. Input summarization. The various inputs are printed out. Some summarizations of the land use variables are output by superzones as specified by the user.

2. Trip generations. Trip generations and attractions by purpose by zone are printed out and also summarized by superzones. The calculated factors that are used to balance total attractions against total generations for each trip purpose are also printed out.

3. Minimum path output. For the transit and road networks the original link data is printed out. Sample minimum time path routes, as specified by the user, are printed out so that the trees can be checked; the paths are printed out by tracing the nodes of the path from destination back to origin so that a number of paths can be easily checked through the creation of a "tree". Also, the user can specify a certain number of zones for which the times to all other zonal centroids will be printed out. A further error checking routine prints out, for each node, the number of links leading to each node and the number of links leading out of each node. Also, a list of those nodes for which the "ins" do not match the "outs" is provided. This is very useful for checking the accuracy of coding and keypunching of the networks.

4. Distribution Outputs. For each purpose, the various parameters of the distribution are printed out. These include, for each zone, the generations, the attractions, and the intra-zonal trips. In addition, the number of iterations required for balancing and the difference on the last iteration between the input attractions and the computed attractions for each zone are printed.

5. Modal split. A summary of modal split information is printed for each purpose in addition to trip length distributions by purpose by mode.

6. Load tables. For the road and transit networks the assigned load, in persons for the transit table, and in vehicles for the automobile table, are provided for each link. In addition there are summaries of person or vehicle kilometers by link type.

7. Superzone summaries. The interchanges between super zones by road and transit are printed out as well as summaries of the numbers of trips generated and attracted in each superzone and the average length of each.

5. APPLICATION REQUIREMENTS

5.1 Computer Requirements

IBIMOD was developed on an IBM 360 computer system. However, the program is written completely in Fortran. It currently runs approximately 25,000 statements. At present, the program can handle up to 170 zones, 900 road nodes and 1,100 transit nodes and requires 300k of storage in addition to a number of disk files. It has been run successfully on various time-sharing systems. A typical run using 150 active zones carried out on an IBM 370 Model 168 required 2.7 minutes of CPU time and 1 minute of channel time, for a total commercial cost of about $80.

5.2 Time and Staff Requirements

Because it is a one step computer model, the JCL requirements for submission of programs are much reduced over comparable systems (e.g. staff time reduced by half). Coding time, on the other hand, is relatively similar as the amount of information required is similar. As the program is written in Fortran it can be easily modified by the analyst to provide specialized outputs or computations.

Calibration is the longest and most time consuming portion of applying this model. In recent applications it has required one to two months of calendar time once the data base has been acquired.

6. APPLICATIONS

The model has been applied to practical problems in Mississauga, the Regions of Durham, York, and Hamilton-Wentworth in the Toronto area, Regina and Bogota, Colombia. Because it is coded in Fortran, it is relatively transferrable from one computer system to another.

7. BIBLIOGRAPHY

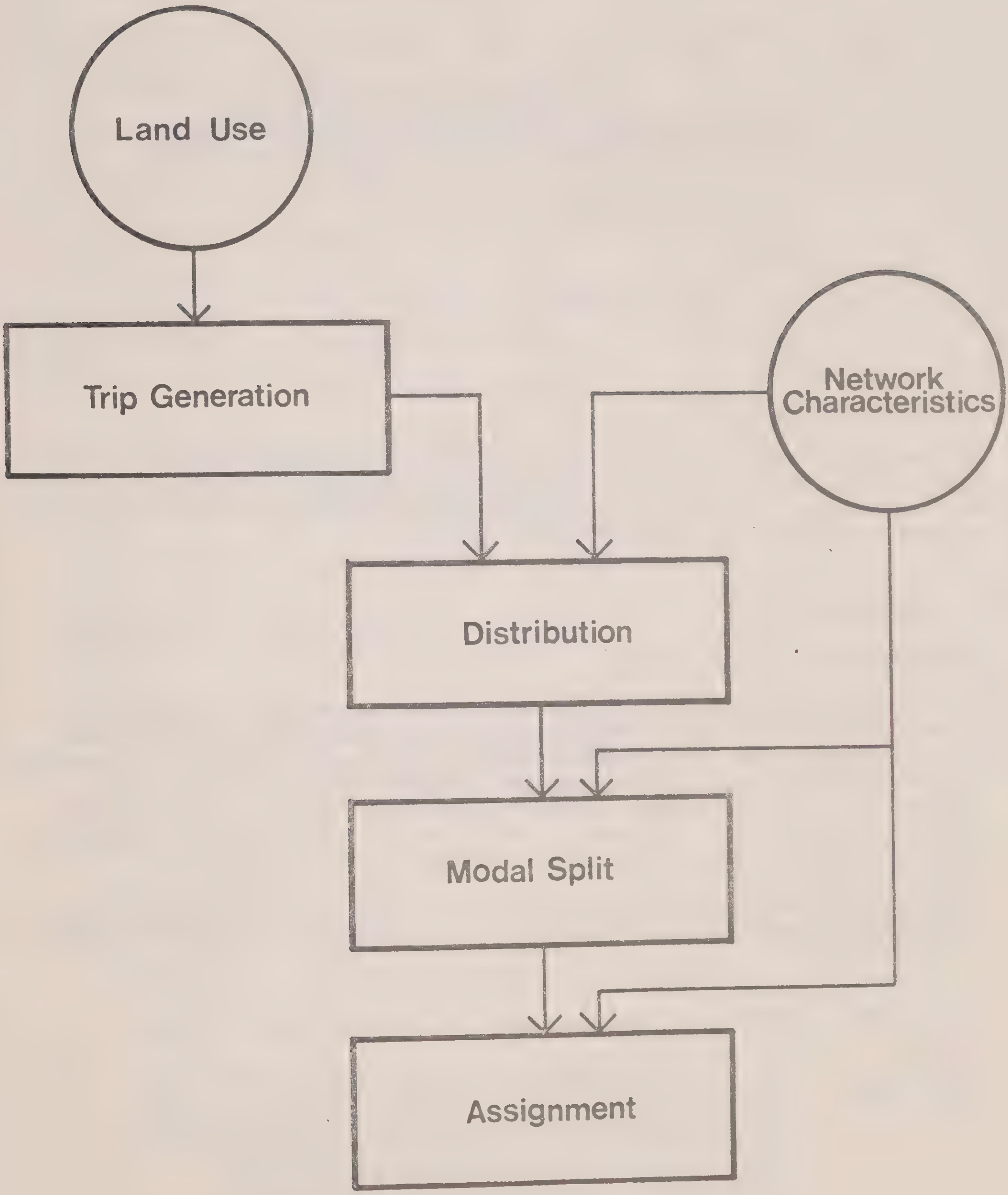
1. Duncan W. Allen, IBI Group, Toronto, "A Comparison of Two Travel Demand Models Applied in Ontario", a paper presented at the Canadian Operational Research Society National Conference, May, 1976.

2. IBI Group, Toronto, "IBIMOD, Users' Guide", second version, January, 1978.

3. Ministry of Transportation and Communications, Ontario, "IBIMOD, Users' Guide", January, 1976

4. Durham Region Planning and Development Department, Regional Transportation Study, Working Paper No. 3, "Transportation Model Development", January, 1976.

EXHIBIT 1
TRANSPORTATION MODEL STRUCTURE



1. TITLE:

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3. AVAILABILITY OF MODEL

The computer programs which are listed in this documentation and the user's manuals associated with them are available to government agencies, universities and Consultants on request. The models listed are fully operational and are generally documented in a comprehensive manner.

4. MODEL DESCRIPTIONS

Transportation Planning System

The Transportation Planning System (TPS) used by the Ministry was developed between 1968 and 1970 by the Ministry and Alan M. Voorhees and Associates, and includes programs for data bank, road/transit network building, trip generation, trip distribution, modal split and table manipulation. The programs were designed for large urban area studies, can handle studies with up to 1500 traffic zones, and will accommodate transit networks with up to five separate modes of transit. There are about 70 programs in this package.

These programs are grouped into five different systems on a functional basis. Each system is described briefly below and the programs within each system are listed.

SYSTEM TITLE:	Municipal Planning Data	NO. 019
SYSTEM DESCRIPTION:	This is a data generation and retrieval system. Planning data is extracted from the Standard Assessment System (SAS) file by municipality and retained on the Basic Planning File (BPF). Standard and generalized reports are printed from the BPF. Standard reports are prepared annually.	

PROGRAM LIBRARY: TCSP.TRAFLIB NO. OF PROGRAMS: 11

SYSTEM COORDINATOR: N.J. Varmazis TELEPHONE: (416) 248-3423

PROGRAM	PROGRAM TITLE
TR01901	Population reports from BPF files
TR01907	Generalized BPF Reports
TR01908	Generalized Basic Planning (File Reports)
TR01912	BPF Generation
TR01918	Sort the BPF
TR01919	Basic Planning File Merge
TR01942	Conversion File Update
TR01952	Address Ranges from Conversion Files
TR01981	Garin - Lowry Land Use Model
TR01982	Geocode Property Zone Conversion File Generation
TR01983	Zone Definition by Coordinates

SYSTEM TITLE: Origin/Destination Survey Processing NO: 021

SYSTEM DESCRIPTION: O/D Survey records are edited, screened, user modified and factored. Used to prepare input to trip table builder. Also contains components of the automatic address identification system.

SYSTEM COORDINATOR: M.J. Varmazis TELEPHONE (416) 248-3423

PROGRAM	PROGRAM TITLE
TR02104	O/D Survey Record Data Preparation
TR02118	License Plate Trace Program
TRO-2122	O/D Survey Record Screening
TRO-2123	O/D Survey Record Manipulation

TR02124	Zone Record Conversion
TR02130	A.A.I.S. Analyser
TR02140	A.A.I.S. Matching Program

SYSTEM TITLE: Traffic Data Bank (T.D.B.) NO: 023

SYSTEM DESCRIPTION: G.P.D.B. - General Purpose Data Bank. A series of programs designed to manipulate data grouped about an identity number such as traffic zone for land use, record number for surveys, etc. Predetermined report, plot and manipulation programs are available.

PROGRAM LIBRARY: TCSP.TRAFLIB NO. OF PROGRAMS: 11

SYSTEM COORDINATOR: N.J. Varmazis TELEPHONE: (416) 248-3423

PROGRAM	PROGRAM TITLE
TR02309	Employment Bank by Physical Property Code
TR02310	Land Use Acreage Inventory Data Bank
TR02311	Build/Update Traffic Data Bank (T.D.B.)
TR02312	Trip Index Generation T.D.B.
TR02313	Zone-District Compression T.D.B.
TR02314	Multiple Regression Analysis T.D.B.
TR02315	P and A Calculation using Regression Equation
TR02316	Reporting and Plotting T.D.B.
TR02317	T.D.B. File and Merge
TR02318	T.D.B. Mapping
TR02319	Population Allocation of a T.D.B.

SYSTEM TITLE: Public Transit Planning NO: 024

SYSTEM DESCRIPTION: O/D survey data is used to prepare input productions and attractions which are distributed using a gravity model formulation. Trees are computed for a given network and based on minimum O/D times, the network is loaded with the distributed trips.

PROGRAM LIBRARY: TCSP.TRAFLIB NO. OF PROGRAMS: 12

SYSTEM COORDINATOR: N.S. Varmazis TELEPHONE: (416) 248-3423

PROGRAM	PROGRAM TITLE
TRO2451	Transit Network Program
TRO2452	Transit Path Finder
TRO2453	Minimum Path Summary Program
TRO2455	Trip Tables/Skim Trees Formatter
TRO2459	Transit Assignment Program
TRO2460	Transit Assignment Report Program
TRO2463	Station to Station Volumes
TRO2464	Merge O/D Survey Record
TRO2467	General Purpose Summary Program
TRO2468	Trip Table Compare
TRO2469	Skim Tree Update
TRO2470	Linear Interpolation Modal Split - Multipurpose

SYSTEM TITLE: Road Transportation Planning NO: 025

SYSTEM DESCRIPTION: The System uses O/D Survey data to prepare input production and attractions which are distributed using a gravity model formula. Road networks are defined by means of numbered intersections. Minimum paths are found for all O/D's and trips are assigned to the road segments which comprise the paths.

PROGRAM LIBRARY: TCSP.TRAFLIB NO. OF PROGRAMS: 31

SYSTEM COORDINATOR: N.J. VARMAZIS TELEPHONE: (416) 248-3423

PROGRAM	PROGRAM TITLE
TRO2501	Print Trip Table
TRO2502	Gravity Model Multifunction
TRO2503	Trip Length Distribution

TR02504	Trip Table Balancing - Fratar
TR02505	Trip End Summary
TR02506	Network BUILD/UPDATE
TR02507	Trip Splitter and Matrix Transportation
TR02509	Skim Trees Builder
TR02510	Gravity Model Multipurpose
TR02512	Modification of Trip Tables
TR02513	Trip Table Compressor
TR02515	Trip Table Manipulator
TR02518	Zone Splitting
TR02520	Sub-Area Trip Table Generation
TR02522	Stack/Modify O/D Tables
TR02523	Trip Table Balancing and Forecasting
TR02524	Sub-Area Network Isolation
TR02525	Multi-Assignment with Capacity Restraint
TR02526	Multi-Path Tree Building and Assignment
TR02527	Speed Adjustment Curves
TR02530	Network Volume Manipulation
TR02531	Origin Destination Trip Comparison
TR02532	Tree and Network Plotter Program
TR02533	Trip Table Builder
TR02534	Matrix Addition
TR02535	Matrix Printout
TR02536	Coordinate Conversion
TR02537	Matrix Exponential Interpolation
TR02538	Weighted Avg. Growth Factor Generator

TR02539 Summation of Selected Link Assignments

TR02540 PMP-IBI Traffic Prediction Program

SYSTEM TITLE: Simplified Transportation Planning NO:033

SYSTEM DESCRIPTION: This system contains a group of six programs which are used to provide transit and road capability for small networks. Many of the features of System 021, 023, 024, and 025 are included in this set of programs. The basic functions are: build a databank, build networks and trees, modal split, gravity model distribution, network loading, O/D survey analysis and traffic surveys analysis plus more.

PROGRAM LIBRARY: TCSP.TRAFLIB NO. OF PROGRAMS: 6

SYSTEM COORDINATOR: N.J. VARMAZIS TELEPHONE: (416) 248-3423

Because of the size of the TPS, a large computer, experienced staff, and a lot of time are required to use the system. MTC felt that these 'heavy duty' computer programs were too costly and time consuming for situations where 'light duty' programs were required. In order to make the TPS programs essentially available to the regional municipalities, universities, community colleges, and consultants, the Ministry combined and streamlined a number of programs from the TPS to form the Simplified Transportation Planning Computer Programs - STPCP (System 033).

The STPCP has the following advantages:

(1) easier for the analyst to code and process the Programs

(2) will handle up to five trip purposes at the same time

(3) room for future expansion

(4) very flexible in terms of available combinations of options and parameters

(5) complete compatibility with the existing TPS programs of MTC

(6) can be used on a medium size computer

(7) lower data processing cost

(8) faster turnaround and resulting elapsed time savings.

The Design criteria and program limitations for the STPCP are as follows:

(1) The programs can be used on computers with a capacity of 200K bytes of core.

(2) The user should theoretically be able to set up a computer run that would start with land use input and trip generation techniques, and finish with road vehicle and transit person assignments to the road and transit networks.

(3) The programs are designed for up to 300 traffic zones and up to five trip purposes. The limiting numbers of nodes and links for road network are 1,200 and 3,500 respectively. For the transit network the limits are 1,200 and 3,000 respectively.

(4) The STPCP programs are written for use on IBM computers, as are the programs in the TPS.

There are six basic programs in the STPCP:

(1) <u>TR03301 - Land Use Data Bank and Trip Generation</u>

This program is used to store and modify land use variables by traffic zone in the study area, and to perform various trip generation techniques based on these land use variables or derivations of these variables. There is an option to perform various manipulation techniques, add productions or attractions for special generators such as airports, universities, and shopping centres, and to choose a final balanced set of production and attraction trip ends for each traffic zone.

(2) <u>TR03302 - Road Network</u>

A road network is built from a description of the characteristics of all road links in the network, and from this network, a set of minimum time and/or distance paths called trees, are built. These trees describe the path from a zone to every other zone in terms of a link by link description. From the trees skims, which are matrices of a minimum times and/or distances from all zones to every other zone, are generated. An AM, PM or OFF Peak network can be built as the user wishes. The algorithm for loading or assigning vehicle trips to the road network is also included in TR03302; the assignment is an all or nothing assignment, i.e. all the trips between the two zones are assigned to the route with the shortest travel time and/or distance, and the speeds on the route are assumed to be independent of the traffic volume.

(3) <u>TR03303 - Transit Network</u>

The programs is similar in structure to TR003302, except that instead of working with only one mode, road vehicles, it works on a number of different transit modes at the same time. The transit assignment option is also included in this program.

(4) <u>TR03304 - Trip Distribution and Modal Split</u>

The gravity model is the basis for the trip distribution procedure in the program. Modal split is performed after the trip distribution phase, and the resulting trip tables are transformed into (1) road vehicle origin destination trips (depending on estimated car occupancy for each trip purpose, (2) transit person origin destination

trips, (3) total person origin destination trips. These are the trip tables that are used in the assignment phase of the TR03302 and TR03303 programs. The program can process five trip purposes at the same time.

(5) TR03305 - Table Manipulation

Trip tables in square matrix form may be added together or modified in a fairly simple manner, stacked together onto one tape, aggregated on a district rather than zone basis, and printed out in matrix form.

(6) TR03306 - Traffic Count and O/D Survey Analysis

This program is used to store and modify the data of a traffic survey, O/D survey or for that matter any survey and questionnaire. The program is very similar to TR03301 however all the functions related to trip generation have been removed in order to allow room for functions related to traffic surveys. The program accepts either a predefined (suggested) format or a user specified format. It produces standard traffic summary reports, cross-tabulations of traffic counts and user-coded reports.

SYSTEM TITLE: Priority Planning NO: 037

SYSTEM DESCRIPTION: A system used to record, evaluate, and prioritize Road Construction Projects from an Economic Need and Available Budget Point of View.

PROGRAM LIBRARY: TCSP.TRAFLIB NO. OF PROGRAMS: 19

SYSTEM COORDINATOR: D.C. Weeks TELEPHONE: (416) 248-3877

In addition to transportation simulation models, the MTC has a "Priority Planning" package of programs. This system (No. 037) identifies and assesses transportation improvement impacts affecting both transportation users and the community at large. Such impacts (i.e. benefits and disbenefits) are evaluated and used to develop time streams of present worth of benefits as a function of the year of implementation. The functional benefit and cost time streams are combined with future budget estimates and subjected to linear programming analysis. The linear program selects and stages a mix of transportation improvements so as to maximize the total present worth of benefits capable of being realized, given the assumed budgets. In assessing the priorities of transportation improvements, the linear program deals with three basic inputs.

1. Benefits (and Disbenefits) — Benefits, including negative benefits such as social and environmental impacts, were classified in the following categories: regional development, user, operator, social, environmental, and right-of-way. Typical examples of benefits include travel-time savings,

operations cost reductions, and increased transit mobility. Disbenefits include neighbourhood disruption, noise, and air pollution. The linear program requires, for each candidate investment, the composite of the present worth of all benefits and disbenefits over the planning horizon for each possible implementation year in the budget period.

2. Costs —— Costs include expenditures for capital construction and continuing maintenance. The costs differ for each year of implementation in the planning period and must be supplied to the linear program in base-year dollars for each implementation year.

3. Budgets —— Estimates must be made of available budgets for each time period and supplied to the linear program in base-year dollars.

While the quantification of such variables as travel time and cost savings is conceptually a relatively straightforward procedure, the quantification of effects such as social and environmental impacts presents a problem. An approach to this estimation is:

$$\text{Benefit or Disbenefit (Value Equivalent)} = Q \cdot S \cdot C$$

where:

Q = quantity — a measure of the amount of change that occurs due to the introduction of an improvement.

S = sensitivity — the relative sensitivity of the community concerned to quantity of the impact.

C = cost — the cost of preventing the impact, replacement cost, or a value judgement.

A priority analysis output contains the optimum schedule, a sensitivity analysis to input data variation, together with a full economic analysis on each improvement relating return on investment to expenditure. Included also is a net value of the benefits foregone or the costs incurred, if an improvement's position in the schedule must be altered.

A budget analysis provides the sensitivity of altering the total budget constraint in any time period by displaying the corresponding changes in return, as well as the respective improvments deferred or added to the program.

The specific programs within the system are listed below:

PROGRAM	PROGRAM TITLE
TR03701	Edit/Update Priority Methodology
TR03702	Inflate/Discount Priority Methodology

TR03703	MPSX Data Preparation
TR03704	MPSX Control Statement Preparation
TR03705	Traffic Volume Frequencies
TR03706	Road User Benefits
TR03707	Transportation Simulator and Cash Flow Evaluator
TR03711	Summary of Cost & Benefit of L.P. Solution
TR03712	Calcomp Plots of Benefits Budgets
TR03713	Calcomp Plot of Cost and Benefit Distributions
TR03714	Summary of Inflate/Discount (Cost/Benefit Ratios)
TR03715	L.P. Solution Scheduled Non-Scheduled Reports
TR03716	Copy-Priority Methodology
TR03717	5 Year Program Fiscal Cost Summary
TR03718	5 Year Program Fiscal Cost Summary
TR03719	Working Improvement List Rewriter
TR03731	Highway Inventory T.D.B. Processing
TR03732	Cost and Mileage by Improvement Type
TR03733	Combine Highway Section on a G.P.D.B.

5. APPLICATION REQUIREMENTS

All of the programs listed were developed for use on IBM computers. The TPS package must be run on a large installation since it has core requirements of 500K. On the other hand the STPCP (System 033) package has a core requirement of 200K and can be run on medium-sized installations. The 'Priority Planning' system can also be run on a medium sized installation, however some of the programs in the system require a calcomp plotter.

The time required to initially implement the TPS package has been estimated to be 4-6 months, while requirements for the STPCP package are roughly half that amount. The turn-around times for modifications to the initial run are 6-8 weeks for the former package and 2-4 weeks for the latter. The effort required to apply the 'Priority Planning' system would depend upon the number of improvements which are being considered and the detail of the analysis.

6. APPLICATIONS

The application of the TPS package has been limited mainly to the TARMS study area, consisting of Metropolitan Toronto and the urbanized parts of the Regions of Durham, York, Peel, Halton and Hamilton - Wentworth. The STPCP (System 033) package has been used, or is being implemented by the Regional Municipalities of Durham, Peel, Halton, Hamilton - Wentworth and Ottawa - Carleton. The Kitchener Area Highway Planning Study was used as the data base source to test and evaluate the 'Priority Planning' System.

7. BIBLIOGRAPHY

Extensive documentation on programs listed earlier is available from the Ministry of Transportation & Communications, Ontario.

APPENDIX D

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